RESEARCH BULLETIN

NUMBER 4 JANUARY 1964

The RESEARCH BULLETIN
is a publication of
The American Foundation for the Blind
15 West 16th Street
New York 11, New York

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Editor

Price per issue $1.50

AMERICAN FOUNDATION FOR THE BLIND, INC.
15 WEST 16th STREET
NEW YORK, N. Y. 10011

PREFATORY NOTE

The *Research Bulletin* of the American Foundation for the Blind is intended to be a means of publication for some scientific papers which, for a variety of reasons, may not reach the members of the research community to whom they may prove most useful or helpful. Among these papers one may include theses and dissertations of students, reports from research projects which the Foundation has initiated or contracted for, and reports from other sources which, we feel, merit wider dissemination. Only a few of these find their way even into journals which do not circulate widely; others may never be published because of their length or because of lack of interest in their subject matter.

The *Research Bulletin* thus contains both papers written especially for us and papers previously published elsewhere. The principal focus may be psychological, sociological, technological, or demographic. The primary criterion for selection is that the subject matter should be of interest to researchers seeking information relevant to some aspect or problem of visual impairment; papers must also meet generally accepted standards of research competence.

Since these are the only standards for selection, the papers published here do not necessarily reflect the opinion of the Trustees and staff of the American Foundation for the Blind.

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Since our aim is to maximize the usefulness of this publication to the research community, we solicit materials from every scientific field, and we will welcome reactions to published articles.

M. Robert Barnett
Executive Director
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for the Blind

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A PSYCHOACOUSTIC STUDY OF FACTORS AFFECTING HUMAN ECHOLOCATION*

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THE CURRENT STATUS OF ECHOLOCATION

For years work has been done to discover how certain animals manage to negotiate in complete or total darkness. It has been found that most bats, many fish, and some birds do possess a means of sensing obstacles and obtaining food even though they might be blind or in total darkness. Professor Donald R. Griffin (17, 18) has made an extensive study of animals of this type which depend upon their hearing for orientation. In many cases the animals emit pulses of sound and listen for the echoes. In other cases it is not certain whether echoes or sounds from active sound sources play a more prominent role in the acoustic orientation. The degree of proficiency in this type of orientation varies among the different animals and seems to be greatest in certain types of bats. These flying mammals do their echolocating with sounds which are predominantly ultrasonic. They have highly developed auditory organs and nervous systems, and specialized vocal systems for producing short, frequency modulated pulses of sound. Their resolution is remarkable. Some of the most highly skilled bats are able to avoid wires smaller than 1 millimeter in diameter and capture hundreds of tiny airborne insects in a single night.

Many blind men have also been able to perform exceptional feats of orientation without dependence upon the sense of vision. Until 1940 a controversy raged over the basis of this ability. Then several graduate students at Cornell University performed a series of rigorous experiments and determined that hearing was the necessary and sufficient sense that enables a sightless person to detect obstacles (1, 15, 19, 30, 36, 40). Further study of the obstacle detection ability has given evidence that there are several characteristics of the sound field which make it possible. First there are the reflections of sounds being produced by the subject as he walks toward the object. Footsteps, rustling of clothes, a cane's tapping, or snapping of fingers all can be used as sound sources. Then there is the sound shadow cast by the object for the random noise in the room. The reflected sound is

*This publication is based on a thesis submitted in partial fulfillment of a Master of Science Degree at the Massachusetts Institute of Technology, Department of Electrical Engineering.

not apparent as an echo, since at the most it can be detected only as a subtle change by the listener's sense of hearing. In fact the listener is seldom aware that his ears play any part in the detection. He often experiences a sensation of facial pressure and is not aware of a change in sound.

Acoustic obstacle detection is now being taught in schools for the blind (10, 42) and studied by various agencies for the blind. It is known that hearing in the 8000 to 10,000 cps range is important to this ability. Furthermore, increases in atmospheric pressure and humidity enhance the ability, while increases in wind velocity and background noise reduce it. There has been no careful quantitative study of these parameters, but the general tendencies have been verified by many observers (12, 36).

Soon after the discovery that both bats and men could detect obstacles with the aid of their hearing there was great effort expended to copy the bat in order to enhance the echolocation of men. Some experimenters tried to develop sound generators which would give clearer and more distinct echoes. They worked towards producing a source which would generate sound in extremely short pulses and which would radiate with a highly directional beam. They also sought to minimize the amount of sound reaching the user's ears directly from the sound generator (18, 21, 35, 37, 39). Other experimenters worked on sound generators with refinements such as electronic pulsing and automatic scanning. Many of these devices did provide a usable echolocation pulse and often they were received with enthusiasm by blind subjects. They were found to be extremely useful as training aids for new blind and for sighted persons undergoing obstacle detection experiments. However, they were usually discarded soon after the user began to gain confidence in his ability to detect obstacles and orient himself with natural random sounds. There was, further, a lack of desire by blind people to make distracting noises which would call attention to their handicap. In most cases this disadvantage of the sound generator was considered slightly greater than any of its advantages.

There is still another way in which men have been attempting to imitate the bat. Systems have been and are still being developed which transmit a form of radiant energy and then attempt to detect the reflections without using the human ears (5, 8, 11, 13, 29, 33, 41). Some systems employ ultrasonics and others use light. Although some of these devices are capable of giving reliable indications of the presence of reflecting objects and accurate indications of range, they are still unaccepted by blind users for several reasons. They all give very directional readings and continually require the user to scan his surroundings to obtain complete information. Those which present their indications of detection and range to the user's ears through earphones necessarily occlude the user's normal sense of acoustic orientation and thus detract more than they add. They are generally

bulky devices and are necessarily expensive in the small production quantities which their usefulness warrants.

The present state of mobility aids research tends to be very discouraging when looked at from the point of view of device development. The blind man needs a system which will given an instantaneous display of obstacles in his immediate surroundings. A relatively broad field of display is desirable to reduce the need for scanning. A reasonable range is also needed to allow him to move at normal speeds in unknown surroundings. His normal sense of hearing must not be occluded. He must be able to detect step-downs and step-ups and the device should work without drawing attention to the user, if possible.

ECHOLOCATION AND HUMAN HEARING

The approach that will be followed throughout this project will be based on a conviction that the use of hearing is man's best hope of overcoming some of the limitations imposed by blindness. Evolution has not served to prepare man for a life of sightlessness, but with careful study and an application of the tools of modern science it may be possible to enhance the ability of the ears to do some of the work normally done with the eyes. The men who study bats certainly must have this in mind as they strive to determine how and why the bat does what it does. Anything that they discover may be of great value to the promotion of human echolocation. The men who study human hearing, however, are seldom motivated by a desire to use hearing to partially replace vision. It is for this reason that little is known about the human potential for echolocation. This thesis is intended as a basic study into some of the factors which might affect the human ability to echolocate.

How might human echolocation operate? It will require a sound source and an extremely sensitive detector. The sound source presents no insurmountable problem. With present day electrostatic speakers and electronic function generators virtually any desired sounds can be synthesized. It would even be possible to produce the sound of a bat scaled down to human frequencies if this were found to be desirable. The detector, on the other hand, presents a much more difficult problem. It must respond to minute frequency and amplitude changes, should preferably be binaural, and should have an output easily coded for human understanding. A perfect choice is the human auditory system. An electronic device which could match man's ability to detect faint sounds and minute frequency changes and perform binaural localization would be difficult to devise.

Unfortunately human hearing has one characteristic which severely limits its echo detection abilities. It cannot detect the second of two closely spaced sounds if the time interval between the sounds is sufficiently small. It is even more difficult to

detect the second sound if the first sound is of appreciably greater amplitude than the second (28). Echoes from close objects have both of these characteristics; the echo closely follows the emitted sound and is diminished in amplitude. This echo suppression characteristic of human hearing is useful for communication purposes since it aids the understanding of speech and music in highly reverberatory surroundings, but it is quite detrimental to any attempt to extract information from echoes themselves.

The explanation for the inability to hear the second of two closely spaced clicks is that the nerve cells which are sensitive to temporal excitations are refractory for a period of time after being excited (9). If the second of two clicks occurs during the refractory period of a particular cell the cell cannot respond. If many of the cells are refractory at the time of the second pulse the total response to the pulse will be greatly diminished. Furthermore, since the number of neurons which respond to an excitation increases when the magnitude of the excitation increases, the masking effect upon the second pulse is increased as the ratio of first pulse to second pulse is increased (24).

Rosenzweig and Rosenblith (28) have reported the following psychophysical observations. When a pulse train consisting of closely spaced, equal intensity double clicks is presented to only one ear, the double clicks seem to fuse into one when the time separation between the clicks is reduced below about 10 milliseconds. When the same pulse train is presented dichotically, that is, with one of the two clicks presented to one ear and the other presented to the opposite ear, the clicks remain distinguishable until the time interval between them is reduced to about 2 milliseconds. For smaller intervals their sounds fuse into one. Between 2 and 10 milliseconds of separation the first of the two dichotically presented clicks is louder than the second, but at 10 millisconds and above they are of equal loudness. With both kinds of presentation increasing the amplitude of the first click with respect to the second increases the maximum time interval for which the clicks fuse into one.

This characteristic of hearing seems to present a formidable limitation to the human potential for echolocation. Any sound generator capable of having a strong echo will invariably produce enough sound at the user's ear to mask all but relatively long delay echoes. It is possible that this is one of the major reasons why all the mechanical click generators and electronic sound sources have met with little success.

There is, however, another characteristic of human hearing which may compensate for the inability to hear short delay echoes. This phenomenon will be referred to as "Thurlow pitch," after W. R. Thurlow, who first reported it (31, 32).

When two clicks are presented to the ear so closely spaced

that they fuse into one, a sound is heard which has a definite pitch. The frequency heard is that which has a period equal to the time of separation of the two clicks; thus the observed pitch varies inversely with click separation. The sensation of pitch has been found to be more prominent if the double clicks are presented repeatedly in a pulse train than when presented as an isolated pair. It is also more prominent when the first of the two clicks is smaller than the second. This ability to hear repeated sounds as a change in pitch may make echolocation of close obstacles possible even though a distinct echo cannot be heard. The existence of a pitchlike quality in the sound of an emitted pulse would indicate the presence of a reflecting object. The pitch itself would give a measure of the distance from sound source to object.

It is highly possible that this pitch sensation is the cue which enables a blind person to detect obstacles with his so-called facial vision. The sensation of pitch produced by echoes of random environmental sounds could be subtle enough to go unheard and yet still be detected as some sort of environmental change indicating the presence of an obstacle.

A third characteristic of hearing which may strongly affect echolocation is the ability to perform binaural localization (20). It has been found that bats lose most of their ability to avoid small objects when one of their ears is covered (17). They can still locate a wall and make a safe landing but they are so disoriented that they usually refuse to fly. Little study has been made of blind obstacle detection with one ear covered, and therefore the importance of binaural hearing has never been emphasized with respect to human echolocation. It seems certain, however, that it would be as essential to humans as it is to bats.

SPECULATIONS AND PROPOSALS FOR THE STUDY OF HUMAN ECHOLOCATION

The echolocation system envisioned in this thesis would have the following general form. The user would be equipped with a sound pulse generator which would radiate with a moderately wide beam. He would then use his ears to locate reflections of objects lying in the sound field. This basic system, which is not new, would depend for its success upon several innovations which will be introduced and studied in this thesis.

The first innovation is a method to reduce the masking effect of an emitted pulse upon its echo. It has been pointed out that the sound of the emitted pulse greatly reduces the ability of the ear to hear an echo and that it also reduces the ability of the ear to detect the Thurlow pitch phenomenon associated with small-time delay echoes. An electronic system which will greatly attenuate the sound of the emitted pulse to the ears of the user is going to be considered. This device, which is explained under

"Possible Future Developments," will not be constructed as a part of this thesis, however, since the thesis object will be merely to study the feasibility of this and other devices. If it is found by psychoacoustic testing that attenuation of the first of a series of two pulses increases the ability to detect and locate the second or echo pulse, the first pulse attenuator may then be constructed.

The second innovation will be an attempt to definitely utilize Thurlow pitch for the detection of short-time delay echoes. The factors affecting the ability to hear a pitch in the presence of an echo will be studied and consideration will be given to the practical utilization of this ability. A particular factor which might affect the detection of Thurlow pitch is the sound pulse repetition rate. When the object to be echolocated is a distant one there may be some advantage to having a slow repetition rate so that range determination might more easily be accomplished. This would also leave more time for the ear to perform its normal functions. When, on the other hand, the object of interest is approached more closely, and the echo becomes apparent as a pitch change, it may be more easily distinguished if the pulse is emitted with a high repetition rate. If true, this might help to explain why a bat increases its repetition rate when approaching an obstacle.

The third innovation is a consideration of the geometry of the echolocation system and its relationship to binaural localization of reflected sounds. The ability to hear an echo-like sound would possibly be enhanced if the echo were displaced spatially with respect to the emitted sound pulse. The ability to locate a source of reflected sound might also be improved if the listener could be provided with a zero axis reference. Certainly the bat has such an arrangement; its sounds are emitted through mouth or nostrils, which are centrally located with respect to its ears. When the bat moves its head its sound generator moves as well and it may be able to locate objects by nulling them with respect to the sound source. When the bat has achieved zero binaural displacement of the echo with respect to its own sounds, it would have a certain indication that the object was straight ahead. For close objects the nulling effect might take an even more interesting form. In such case a change in pitch might be the distinguishing quality of an echo. For an object displaced from the center the pitch would be higher for one ear than for the other, since the time delay would be different. To locate the object it might be possible to simply turn the head until the pitch was the same at both ears.

At this stage these theories about the relationships between binaural hearing and echolocation are little more than speculation. If they can be verified by this thesis they may serve as a partial explanation for the failure of hand-held sound generators. A human receives a relatively great amount of localization infor-

mation by making slight movements of his head. If his sound generator were attached to his head it might prove to be much more effective than when held in his hand. Such an arrangement would be highly unsatisfactory, however, unless there were an effective means of reducing the sound of the generator at the ears of the user; thus there is one more reason for considering a device which can attenuate the sound of the emitted pulse.

POSSIBLE FUTURE DEVELOPMENTS

If by psychoacoustic experimentation it can be determined that human echolocation can be aided by one or more of the innovations considered in the previous discussion, it may become feasible to build an echolocation device consisting of a head-mounted sound generator and a system capable of attenuating the emitted sound at the user's ear. Such a device is hereby suggested. Construct a headpiece fitted with two earphones and two microphones. Adjust the earphones to have a soundproof seal so that the amount of sound entering the ear from sources external to the earphones is reduced to a minimum. Mount the microphones as close to the ears as possible so as to provide good quality binaural pickup. Then drive the earphones from the outputs of the microphones using very high quality audio equipment. The entire system should be adjusted so that the individual's hearing through the electronic apparatus is as close to normal hearing as is possible. When this is accomplished it will be a simple matter to shut off the user's hearing whenever a sound pulse is being emitted. By synchronizing an electronic switch with the sound pulse generator, the sound of the pulse could be completely eliminated from the earphones, without eliminating the ability to hear other sounds. Enough ability to hear the first pulse will be provided by leakage, through the earphone seals, to act as a time reference and to give the necessary double sound needed to produce the sensation of Thurlow pitch.

If such a device is built and if it does improve the user's ability to echolocate, further research can be done to determine such things as the effects of various types of sound pulses, the effects of background noise, and the resolving power of the system with a complicated array of obstacles. If after careful optimization of all parameters, the system appears to be something which could actually be of benefit to blind users, there will still be several jobs to be done. First, the device must be packaged into a compact and portable form. Then later an effort should be made to operate with ultrasonic frequencies so as to reduce the tendency of the device to attract attention to the user.

PROPOSED PROGRAM OF INVESTIGATION

The investigations will be conducted as a series of psychoacoustic experiments. Sounds will be generated to simulate the original sound pulses and the echoes of the envisioned echolocation system.

These test sounds will be presented to the subjects through matched and calibrated earphones and the tests will be performed in an anechoic and soundproof room.

The determination of what kind of sound pulse would be optimum will not be attempted. Some consideration has been given to this subject but nothing conclusive has been determined. It seems that other factors are more worthy of investigation at the present preliminary stage. For this reason and for the reason of convenience, short rectangular pulses (called "clicks") will be used for all the investigations.

In all the tests the sounds will be presented as trains of clicks. In order to simplify the discussion of these tests the variables of interest are represented diagrammatically in Figure 1. The click representing the original sound pulse will be presented simultaneously to both ears in all the tests, but the echo pulses will be given a binaural displacement as represented by the time delay τ_b. The echo delay time will be represented as τ_e. The pulse widths will be held constant at 0.1 millisecond so as to be consistent with previous psychoacoustic literature. The echo pulses will be presented to the ear at relatively low level throughout the entire series of tests. The ratio of first pulse to second pulse amplitude is A/B and will be called k_e. Where k_e is varied, B will remain constant and A will be changed. This variation will be analogous to the variation in first pulse amplitude that would be achieved with the proposed electronic hearing apparatus.

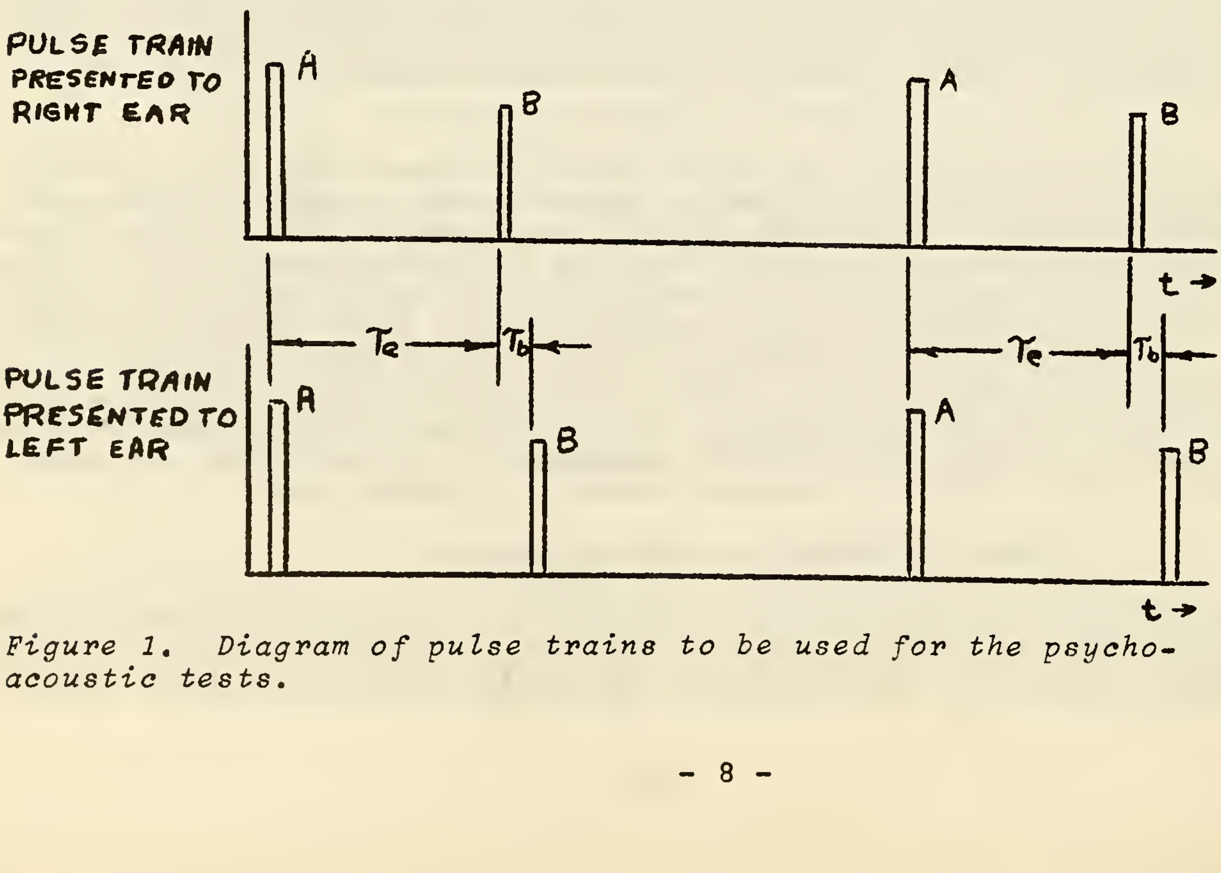

Figure 1. Diagram of pulse trains to be used for the psychoacoustic tests.

It should be noted at this point that, although the electrical input to the earphone may be a rectangular pulse, the pressure wave at the ear will not be rectangular.

The first experimental activity will be to set up the equipment and prepare the anechoic chamber for the testing. Most of the equipment is available and operational in the laboratories of the Communications Biophysics group of the Research Laboratory of Electronics. After the equipment is set up the earphones will be calibrated and checked to make certain that they are matched and that they do present an acceptable pressure wave at the ear.

The first psychoacoustic problem will be to determine by informal experimentation some method for measuring the ability to echolocate. Echolocation consists of detection, location, and range determination. The question is which of these three abilities should be measured. Range determination will not be considered in this preliminary study, since it can be accomplished only after the basic processes of detection and location have been performed. Since detection is also basic to location, it might seem logical to consider some method of measurement that was based merely on the ability to detect an echo-like sound. There are two possible disadvantages to this approach, however. If care were not taken, the subject's extreme sensitivity to changes in an audible display might make it seem that he had a great ability to detect echoes when in reality he was only detecting some subtle change in the sound. The second disadvantage to this method is that the results would actually be threshold measurements. These could be misleading since certain abilities in audition, such as the ability to make temporal discriminations, are much different at threshold than they are above threshold. A measurement of the ability to locate an echo, on the other hand, would not have these disadvantages. It would constitute a more realistic simulation of the actual problem and it would measure relationships above the threshold of detection.

One possible way to test location ability might be to present the pulse train of Figure 1 with τ_b preset at some random value. Then give the subject control over τ_b and request him to adjust his controller until the echo becomes aurally aligned with the sound of the emitted pulse. The ability or inability to locate the echo could then be measured by the variance in his settings of τ_b. This scheme and several others will be investigated by the preliminary informal tests and attempts will be made to select the most reliable measuring techniques for the tests that will follow.

During the period of informal testing it is expected that relationships between some variables and the ability to echolocate will become obvious. For instance, it has been observed that high repetition rates enhance the ability to hear Thurlow pitch. These observations as well as new developments will be absorbed into the findings of this project without formal testing if they

appear to be thoroughly evident.

This will leave more time for careful investigation of some of the more critical relationships.

At present some of the items thought to require careful investigations are:

(a) The effect of echo delay time τ_e, upon the location of echoes.
(b) The effect of k_e upon the location of long delay echoes.
(c) The effect of pulse repetition rate upon the location of short and long delay echoes.
(d) The effect of k_e upon the location of short delay echoes.
(e) The use of binaural nulling to detect and locate echoes.

The first four of these items will probably be investigated by straightforward measurement once a method is devised to measure the ability to locate echoes. The use of binaural nulling will probably be investigated indirectly since it may be the measuring tool for the other investigations.

REFERENCES

1. Ammons, C. H., P. Worchel, and K. M. Dallenbach, "Facial Vision; the Perception of Obstacles Out of Doors by Blindfolded and Blindfolded-Deafened Subjects," Amer. J. Psychol., Vol. 66 (1953), pp. 519-553.

2. Bekesy, G. von, "Current Status of Theories of Hearing," Science, Vol. 123 (1956), pp. 779-783.

3. Bekesy, G. von, and W. A. Rosenblith, "The Early History of Hearing-Observations and Theories," J. Acoust. Soc. Amer., Vol. 20 (1948), pp. 727-748.

4. Bekesy, G. von, and W. A. Rosenblith, "The Mechanical Properties of the Ear," in S. S. Stevens (ed) Handbook of Experimental Psychology. New York: John Wiley and Sons, Inc., 1951, Ch. 27.

5. Beurle, R. L., "Electronic Guiding Aids for Blind People," Electronic Eng., Vol. 23 (1951), pp. 2-7.

6. Boring, E. G. Sensation and Perception in the History of Experimental Psychology. New York: Appleton-Century-Crofts Publishing Company, 1942.

7. Boyle, R. W., S. C. Morgan, and J. F. Lehman, "Audible Sonic Beats from Inaudible Sources," Trans. Roy. Soc. Can. (3rd Series), Vol. 17, Sec. 3 (1923), pp. 141-145.

8. Bradfield, G., "Obstacle Detection using Ultrasonic Waves in Air," Electronic Eng., (December 1949), pp. 464-469.

9. Brucke, E. T. von, M. Early, and A. Forbes, "Recovery of Responsiveness in Motor and Sensory Fibers During the Relative Refractory Period," J. Neurophysiol., Vol. 4 (1951), pp. 80-91.

10. Carroll, T. J. Blindness. Boston, Toronto: Little, Brown and Co., 1961.

11. Cooper, F. S., "Guidance Devices for the Blind," Phys. Today, Vol. 3 (1950), pp. 6-14.

12. Cotzin, M., and K. M. Dallenbach, "Facial Vision; The Role of Pitch and Loudness in the Perception of Obstacles by the Blind," Amer. J. Psychol., Vol. 63 (1950), pp. 485-515.

13. Cranberg, L., "Sensory Aid for the Blind," Electronics, Vol. 19, (March 1946), pp. 116-119.

14. Davis, H., "Biophysics and Physiology of the Inner Ear," Physiol. Rev., Vol. 37 (1957), pp. 1-49.

15. Didea, A., "Detection of Obstacles by Blindfolded Persons," Biol. Rev. (City College, New York), Vol. 9 (1947), pp. 9-15.

16. Frank, W. E., "Instrumentation Requirements in Sensory Aids," Ann. N. Y. Acad. Sci., Vol. 60 (1955), pp. 869-876.

17. Griffin, D. R. Listening in the Dark. New Haven, Connecticut: Yale University Press, 1958.

18. Griffin, D. R. Echoes of Bats and Men. Garden City, New York: Anchor Books, Doubleday and Company, 1959.

19. Hayes, S. P. Facial Vision or the Sense of Obstacles, (publication No. 12). Watertown, Massachusetts: Perkins Institution (Perkins School for the Blind), June, 1935.

20. Kock, W. E., "Binaural Localization and Masking," J. Acoust. Soc. Amer., Vol. 22 (1950), pp. 801-804.

21. Laufer, H., "The Detection of Obstacles with the Aid of Sound Directing Devices," Biol. Rev. (City College, New York), Vol. 10 (1948), pp. 30-39.

22. Licklider, J. C. R., "The Influence of Interaural Phase Relations upon the Masking of Speech by White Noise," J. Acoust. Soc. Amer., Vol. 20 (1948), pp. 150-159.

23. Licklider, J. C. R., "Basic Correlates of the Auditory Stimulus," in S. S. Stevens (ed) Handbook of Experimental Psychology. New York: John Wiley and Sons, Inc., 1951, Ch. 25.

24. McGill, W. J., and W. A. Rosenblith, "Electrical Responses to Two Clicks; a Simple Statistical Interpretation," Bull. Math. Biophys., Vol. 13 (1951), p. 69.

25. Peake, W. T. An Analytical Study of Electric Responses at the Periphery of the Auditory System, (Technical Report No. 365). Cambridge, Mass: Massachusetts Institute of Technology (Research Laboratory of Electronics) March 17, 1960.

26. Polster, H. D., and F. H. Slaymaker, "Diffraction at a Step-down," J. Acoust. Soc. Amer., Vol. 19 (1947), p. 732.

27. Rosenblith, W. A., "Auditory Masking and Fatigue," J. Acoust. Soc. Amer., Vol. 22 (1950), pp. 792-800.

28. Rosenzweig, M. R., and W. A. Rosenblith, "Some Electrophysiological Correlates of the Perception of Successive Clicks," J. Acoust. Soc. Amer., Vol. 22 (1950), pp. 878-880.

29. Slaymaker, F. H., and W. F. Meeker, "Blind Guidance by Ultrasonics," Electronics, Vol. 21 (May 1948), pp. 76-80.

30. Supa, M., M. Cotzin, and K. M. Dallenbach, "'Facial Vision.' The Perception of Obstacles by the Blind," Amer. J. Psychol., Vol. 57 (1944), pp. 133-183.

31. Thurlow, W. R., and A. M. Small, "Pitch Perception for Certain Periodic Auditory Stimuli," J. Acoust. Soc. Amer., Vol. 27 (1955), pp. 132-137.

32. Thurlow, W. R., "Further Observation on Pitch Associated with a Time Difference between Two Pulse Trains," J. Acoust. Soc. Amer., Vol. 29 (1957), pp. 1310-1311.

33. Twersky, V., "An Obstacle Detecting Device for the Blind," Biol. Rev. (City College, New York), Vol. 9 (1947), pp. 16-21.

34. Twersky, V., "Obstacle Detector vs. Guidance Device," Biol. Rev. (City College, New York), Vol. 11 (1949), pp. 14-19.

35. Twersky, V., "Flashsounds and Aural Constructs for the Blind," Phys. Today, Vol. 4 (1951), pp. 10-16.

36. Twersky, V., "On the Physical Basis of the Perception of Obstacles by the Blind," Amer. J. Psychol., Vol. 64 (1951), pp. 409-416.

37. Twersky, V., "Auxiliary Mechanical Sound Sources for Obstacle Perception by Audition," J. Acoust. Soc. Amer. Vol. 25 (1953), pp. 156-157.

38. Wever, E. G. Theory of Hearing. New York: John Wiley and Sons, Inc., 1949.

39. Witcher, C. M., and L. Washington, "Echo-location for the Blind," Electronics, Vol. 27 (December 1954), pp. 136-137.

40. Worchel, P., and K. M. Dallenbach, "'Facial Vision': Perception of Obstacles by the Deaf-Blind," Amer. J. Psychol., Vol. 60 (1947), pp. 502-553.

41. Zahl, P. A., "New Aids for the Blind," Atlantic Monthly (May 1946), pp. 71-77.

42. Zahl, P. A. (ed). Blindness. Princeton, New Jersey: Princeton University Press, 1950, pp. 576.

ORIENTATION BY AURAL CLUES*

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INTRODUCTION

It is a well-known fact that not only light but also sound may serve as a means of orientation. A number of technical devices have been developed for the purpose of ascertaining sources of sounds (their direction and distance) as well as locating mute objects (by means of artificial sound projection and measuring the echo).

What may be achieved by technical means and devices had, however, been achieved by natural sense organs a long time ago. The best-known biological examples of the utilization of sound waves for the purpose of orientation within space are the flying by night of bats, and recently of a species of swallow, namely the oil bird (Steatornis), as well as the ability of walking about alone and without aid which is characteristic of many blind people. In the former case the mechanism of orientation was fully explained by Griffin and Galambos (10, 11, 12). The latter case has given rise to doubts until quite recently. Though several decades ago Truschel (27) and Dolansky (7) declared that the faculty of orientation of blind persons is due to their sense of hearing, the acoustic source of the human "obstacle sense of the blind" was confirmed by experiment only by the extensive research work carried out by Dallenbach and his collaborators (1, 5, 26) as well as by research work carried out at the Innsbruck Institute of Experimental Psychology (9, 14, 30).

The terms "obstacle sense," "blind man's sense," "sense of orientation," etc., are misleading, for such terms suggest the existence of a special "sixth sense" for such cases. What is certain is the lone fact of the existence of "blind orientation," which means that certain persons are able to find their way about

*The present work was carried out under a research order placed by the U.S. Air Force, European Office of the ARDC at Brussels, under Contract AF, 61 (514)-889. The following collaborators contributed largely towards achieving the results described: Professor Th. Erismann, Dozent Dr. P. Scheffler, Dr. H. Pfister, Dr. A. Schlismann, the students H. Domes, F. Grill, K. Siller, H. Larwin, and, as an engineer, J. Wirth. The English translation is by Dr. Heller-Merricks.

without the aid of their eyesight. The problem to be solved is to find out upon what sources this ability is based. In any case, the term applied to the phenomenon must not, from the very outset, be charged with any hypothesis. It would therefore be more appropriate to speak of "blind orientation" or, at the most, of "orientation by sound," because at least the acoustic root of the phenomenon is sufficiently firmly established.

In spite of this, however, a sort of "skin sense theory" has been maintained up to the present day. The reason for this is the following: Whereas, in the case of bats and birds that fly by night nobody knows anything at all of the nature of their subjective sensations when they detect obstacles on their flight and therefore avoid them so that experimental results are the only source of knowledge, blind persons are able to describe their experience by making definite statements. These statements, however, seem to indicate that the skin rather than sense of hearing is responsible. Many persons, particularly blind persons who developed a good sense of orientation and could walk about unaccompanied, declared that what they felt in the neighborhood of obstacles was a peculiar sensation of pressure on their skin, particularly on the skin of the face (forehead, temple, cheek).

There can be no doubt about these subjective experiences which one either has or has not; it is, however, doubtful whether a "theory" which is developed at the same time and which alleges that the skin is subjected to the immediate influence of stimuli emanating from the objects in question is justified. This problem can be solved only by special research. It is furthermore not a satisfactory solution simply to ignore the fact of "facial vision"* as soon as it is found as the result of further research work that the faculty of orientation of blind persons can be satisfactorily explained by their sense of hearing. In spite of the essential importance of sense of hearing for the detection of obstacles, it still remains to be explained why this fact does not also form the basis of a subjective experience. Why, therefore, make a "detour" via skin sensations? As long as this problem remains unsolved it cannot be denied that skin sensation theories have some semblance of justification.

The present work makes a point of avoiding the aforementioned problems. Research work in this direction is still going on. The problem at issue is to form an opinion, in principle, *of the possibilities and limits of orientation by means of sound, in which connection the hearing capacity of the human ear (with all its peculiarities) is taken into consideration as "receiver" and "inter-*

*Also this term, as well as such expressions as "facial perception" or "facial sensation" are used. Though they mean nothing else but blind orientation, the main stress is laid on the peculiar sensations on the skin of the face which are mentioned by many blind persons.

preter."

Parallel herewith is the development and application in practice of *sound projectors* ("guide sound devices") which serve, on the one hand to facilitate investigations (advantage of a controllable sound field), and on the other to find out the best conditions for the production of the highest efficiency of human orientation by sound. Investigation thus extends 1) to the phenomenon of orientation by sound itself and to its measurement, 2) to the physical and technical investigation of the optimum conditions of orientation by sound, 3) to the "restrictions" imposed upon the hearing capacity of the human ear, and 4) to practical application.

ORIENTATION BY SOUND AND ITS MEASUREMENT

The fact that among blind people there are some who may be described as being "independent," i.e., that they are able to find their way about without being accompanied by a guide and without having to feel their way by means of their hands or a stick, and that they are able to avoid obstacles, raised the problem of a "sense of orientation" of blind people. It is not only the fact of being quite familiar with one's surroundings and with the routine of walking along the same stretch every day that enables a blind person to move about without aid, but this ability is in addition due to *other sources of information* which alarm and warn him as soon as he ventures too near to a wall, stands in front of a closed door, or when a parked automobile prevents him from crossing a street. It is our task to become acquainted with the nature of this "information," and to find out which of the human organs is the receiver.

There is no need of any great experimental preparations to answer this question. If *hearing capacity* is eliminated (for example by putting a stop into one's ears) blind orientation is eliminated simultaneously. This result has been known since 1909 (27). Since that time it has repeatedly been reinvestigated and confirmed. In the course of our own investigation we eliminated hearing capacity by means of disturbing noises which were transmitted by earphones. This method also paralyzes the capacity of finding one's way about. The "disturbance" itself is on this occasion of no importance for the result obtained. Disturbances which affect other organs without impairing hearing do not impair the sense of orientation.

A considerable number of further proofs was added to these basic results in the course of time.

Tests Carried Out with Persons who are both Deaf and Blind

Worchel and Dallenbach (33) examined a number of subjects who were

both deaf and blind and who were known to be well able to move about freely and without aid in their homes and in familiar surroundings. As soon as they found themselves in the unfamiliar surroundings of the laboratory they failed completely. Thus, the following important postulate must be made in the case of every experimental investigation of the sense of orientation of blind persons: All "clues" that may impart information as to the existence of an obstacle must be kept under control. If it is intended to find out to what extent aural clues contribute towards brining about certain results the obstacle must never be allowed to be disclosed by such clues as any sort of smell, radiation of heat, a breath of wind, or by some unevenness of the ground. If these precautions are neglected wrong results are inevitable. In everyday life there is, of course, no reason why blind persons or persons who are both deaf and blind should not avail themselves of the advantages offered by such "clues," which they often do with great skill. However, on the occasion of tests carried out for the purpose of examining each individual factor separately, other factors must be known and carefully eliminated. If this rule is followed conscientiously, it will be found that as in the case of persons who are both deaf and blind, it is no longer possible to detect obstacles as long as hearing capacity is eliminated. This result is most important because, in addition, it shows that if the outer ear as well as the sense organs in the skin of the auditory passage and on the tympanic membrane are kept free, this fact is of no importance for orientation. (When the ear is stopped up, the auditory passage is also closed, but in this case it remains open.)

Worchel and Berry (34) extended these investigations to deaf subjects who were blindfolded. The result was the same as in the case of persons who are both deaf and blind. These results were also confirmed by our own investigation.

Tests by Masking

In order to supply confirmation of the last-mentioned point also by the inverse method (hearing is allowed to function, but the skin of the face is covered), masking tests have been carried out repeatedly. Dallenbach (26) covered the skin of the faces of his subjects with a layer of felt in order to eliminate pressure waves which might irritate the skin from without. He left a space between the felt cover and the skin, on the one hand in order to avoid an irritation of the skin, on the other in order to mask also the sections of skin in the neighborhood of the ears. We ourselves (9) carried out similar experiments which confirmed the results obtained by Dallenbach: obstacle sense is reduced to exactly the same extent as sound is eliminated. In the case of the investigation carried out by Dallenbach the fact that also the ears were covered up resulted in a slight deterioration of the performance. In our case (i.e., when the auditory passage remains open) no deterioration could be found.

A more radical method than that by masking is that by anesthetization of the skin. After novocaine has been injected into those parts of the skin which are described as being particularly "sensitive" to obstacles, this part of the skin becomes insensitive to exterior influence, but the efficiency of blind orientation is by no means impaired. This is shown by Illustrations 1 and 2: the blind subject is at first sent into a narrow corridor *before* (Figure 1) and *after* (Figure 2) anesthetization of the skin of the face. In order to make proof as convincing as possible we anesthetized only *one-half of the face* in some cases (as e.g., in the one shown on this occasion). Had there been any deterioration of the information imparted in the direction of the anesthetized part of the face, this fact would have immediately manifested itself by the impossibility of keeping to the middle of the corridor while walking along it. Actually, however, the course taken by the subject (made visible by a light on the person's head) shows that such is not the case.

This test is interesting also in connection with skin sensations. Not only the efficiency of blind orientation but also the

Figure 1. Course of travel of blind subject before anesthetization of the face.

peculiar facial skin sensations remain unimpaired in spite of the fact that here the skin is anesthetized.

Some interesting tests were carried out by Potuschak (20) in connection with which the skin of the face was left completely uncovered, but a separating screen was fastened to the temples in order to isolate the ears (Figure 3). After the dimensions of this separating screen had been increased beyond the width of 15 cm, obstacles approached from the front could no longer be detected.

Tests Carried Out by the Diversion of Sound

One of the most convincing proofs of the acoustic root of blind orientation is the pseudophone test. If an apparatus described by Young (35) is used, by means of which the sound path leading to the ear is exchanged (Figure 4), the reaction of blind persons to obstacles is laterally inversed. This test, which was carried out by us several times with equally good success, is also interesting in connection with skin sensations which occur in accordance with the exchanged hearing conditions on that part of the face which is opposed to that on which the obstacle is located.

Dallenbach (5) achieved success even with the following experiments. A blind person walking about in a room had only a microphone on his person which registered the sound made by his steps. Another person was, at the same time, sitting in an adjoining room wearing headphones and, from the transmitted sounds, this person had to register every approach to one of the walls made by the blind person in the other room. The positive result achieved by such experiments also shows that blind orientation is mainly based upon utilization and use of auditory clues.

Results Achieved in Soundproof Cells

Here it is necessary to distinguish between two cases, i.e., whether the cell in question is merely made soundproof, which means that no exterior sounds are able to enter, or whether, in addition, it is "anechoic" (nonreverberant). In the former case results achieved by blind orientation tests are the same as usual; in the latter case certain illusions occur. In the course of a series of tests we found that correct localization and correct estimation of the distance of obstacles diminishes in exactly the same degree to which the sound absorbing properties of an obstacle increase (according to whether cardboard, rubber, felt, soft material, or wadding is used as an "obstacle"). Hard surfaces are here far above the average of detectability with respect to normal (reverberant) rooms. When a guide sound device and a cardboard obstacle of 50 cm diameter were used the soundproof cell (5 m in the diagonal) was found to be too small so that it was not

Figure 2. Course of Travel of blind subject after anesthetization of the face.

Figure 3. Use of a separation screen fastened to the temples to isolate the ears (after Potuschak [20]).

Figure 4. The pseudophone, developed by Young (35), interchanges the sound paths to the ears.

possible to remove the obstacle beyond range of the detectable zone.

In connection with such tests we were obviously also interested in finding out whether it is possible to detect obstacles in absolute stillness. It soon turned out that "absolute stillness" is in itself a problem. The sounds made by breathing are sufficient to facilitate the detection of approaching cardboard obstacles over a distance of more than one decimeter. If a test person holds his breath, a remnant of orientation ability is still retained. This result is probably due to the fact that a minimum of sound still remains even if persons keep perfectly quiet, as e.g., muscular tonus-sounds and perhaps also those of the ear drum, the "echo" of which is felt as a change of sensation which is very difficult to define in relation to a "free feeling around one's head," and which occurs particularly if obstacles are very near. The sensitivity of hearing, after a period of absolute stillness, is of astonishing fineness (compare de Vries [6]).

Measuring the Obstacle Sense

For the purpose of investigating orientation by the ear (with respect to sound-reflecting surfaces) it is advisable to work out a measuring method by means of which it is possible to obtain comparative and quantitative data. The first quantitative investigations were made by Jerome and Proshanski (13) and followed Dallenbach's tests. In the course of these tests blind persons or persons who were blindfolded were sent along a long alley in which a number of irregularly located upright slabs were erected. The subjects had to pass between these obstacles without brushing against them. In front of each of these obstacles the floor was marked, and these markings could be felt by the subject's foot. Only in six cases was such a mark followed by an obstacle; in six other cases the markings were not followed by an obstacle. The subject now had to tell each time his foot detected such a mark whether there was an obstacle behind it or not. The marks were at first placed near the obstacle, and later at a greater distance from it. The tests which were carried out with four blind persons produced the following results:

distance of obstacles	3	4	5	6	7	8	9	feet
correct statements	94	87	87	85	72	50	42	percent

However, this method is not only complicated and requires much time, but it also contains sources of errors which must be eliminated. The sounds caused by walking are a factor which must not be disregarded. Dallenbach discovered, as a result of the first test he carried out, that the distance from which it is possible to detect an obstacle becomes considerably shorter if the subject walks without shoes or if the floor is covered by a rug.

The size of the obstacle's surface is of no less importance. Furthermore, it can hardly be avoided that conclusions are drawn as to the location of obstacles from the nature of the room concerned, from the distance to walls, from the vibrations of the floor, or from sounds caused by shifting test obstacles from one place to another.

We have therefore worked out a measuring method which eliminates the above mentioned sources of errors as far as this is possible (see Figure 5). The subject sits quietly in a chair. The "unit obstacle" (a round cardboard disk with a diameter of 50 cm) is held in front of the person at various distances and without making any noise. It is fastened to a bamboo pole of 5 m length which is operated by the experimenter by a slight pressure of his finger. The device is fixed at its thrust point to a spherical joint so that it can be moved ad libitum in the horizontal and/or vertical direction. A simple writing device (a clockwork with ink recorders) registers the position of the obstacle in each individual case as well as the reactions of the subjects. The subjects were instructed to press a lever each time they believed they could "feel" the presence of an obstacle. The motions performed by the lever were transmitted by a cable line to the registering paper.

Figure 5. The measurement conditions using the "unit obstacle" (see text).

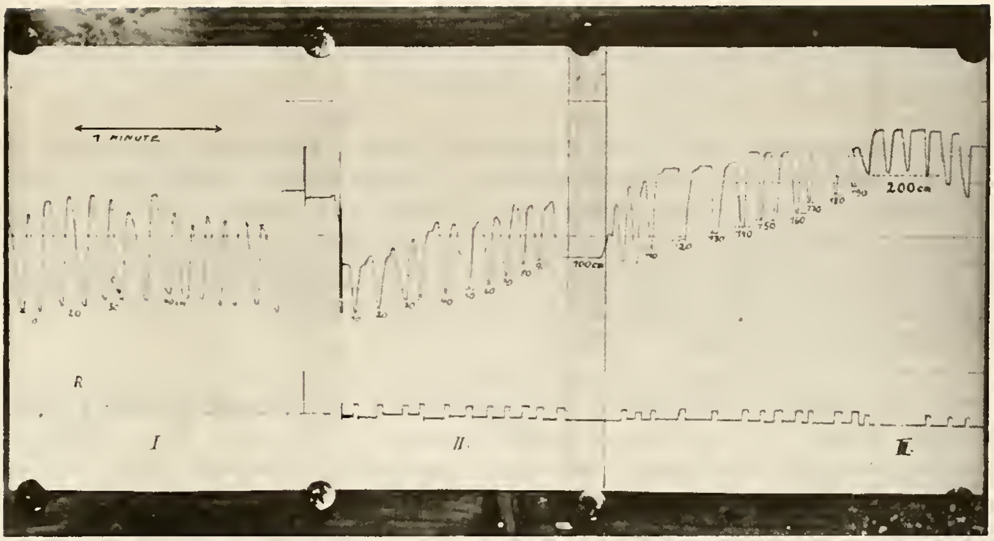

Figure 6. An obstacle position recording obtained under the measurement coditions of Figure 5.

Illustration Figure 6 shows a result obtained by means of the above-described method. The up-and-down course of the line described the up-and-down motions performed by the obstacle. The lowest point of each up-and-down motion corresponds to the horizontal distance of the obstacle from the face of the subject. The bottom line shows the reactions (R) of the subject.

In this way it is possible within a few minutes to ascertain the utmost distance at which a subject is still able to detect the unit obstacle. During this examination the experimenter always made a point of avoiding a "rhythmical" motion of the obstacle, which also may easily be seen from the curve diagram (the course of the line is irregular).

Measuring was carried out in three stages: (I) The test person took a seat and vision was obscured by means of a perfectly light-proof pair of glasses, whereupon the obstacle was several times held in front of the subject's face at a distance of about 10 cm. After this preliminary test the subject was left to react independently as soon as he (or she) detected the obstacle "in any way." Vocal statements were prohibited. In the course of the measuring process the distance of the obstacle was increased until either no reaction could be obtained at all or until hallucinations occurred. In the case of Figure 6 the limit of correct reaction is at a distance of about 20 cm between the obstacle and the face of the subject. At a distance of 30 cm reactions begin to fail. The "index" of the respective test person is therefore at about 25 cm, when it is "just possible" to detect an obstacle.

In the next two stages, II and III, the test was repeated but

in this case a "guide sound device" was used, i.e., the subject wore a small sound emitter round his (or her) neck (see Figure 5) and had to react as before. It may be seen on the first glance that a considerably improved performance is the result. After the obstacle had been removed to a distance of 1 m (stage II) a short pause was made and the seat of the test subject was turned in order to compensate for the ever increasing obliquity of the obstacle surface. In the course of the following (III) stage the limit of detectability was reached. In the example shown by Figure 6 it is at 190 cm. The increase of blind orientation performance when a "guide sound" is used therefore amounts to more than the ninefold in this case.

In the manner described 267 persons aged between 4 and 85 years, among them 50 percent aged between 10 and 35, were examined. Twenty-three percent of the tested persons were people with very weak eyesight, 13 percent had noisy professions (traffic policemen, workmen whose work was connected with a considerable amount of noise, musicians, etc.). The hearing capacity of about 10 percent of these subjects was below the level that would be considered normal at their respective ages.

The following distribution was found on the occasion of the measuring of obstacle sense (a) without using a sonic guiding device, and (b) when using such a device. In the upper line the distances of the standard obstacle which are just still detectable are mentioned (in intervals of 15 cm); the figures below these numbers denote the number of persons who attained this value.

a)

(distances in cm)

0	5-20	20-35	35-50	50-65	65-80	80-95	95-110
178	43	27	12	3	1	2	1

(number of persons)

b)

(distances in cm)

20 -35	-50	-65	-80	-95	-110	-125	-140	-155	-170	-185	-200	-215
3	6	11	27	16	35	37	50	40	21	13	3	5

(number of persons)

Eighty-nine persons, i.e., 33 percent, were from the very outset found to possess obstacle sense, the average value of which is about 8 cm. When using the sonic guiding device all persons were able to detect the obstacle; the average value here was 120 cm.

For the practical utilization of acoustic orientation it is necessary, however, to be able to detect obstacles not only in a *forward direction*, but also if they are approached *laterally*. We therefore some time ago adopted the practice of setting obstacle sense "profiles." On this occasion measurement is carried out in a somewhat freer manner, in that the experimenter holds the unit

obstacle (which is fastened to a rod) in his hand and approaches the subject from various directions. The limits of discernableness found in each case are entered in a form.

The result (Figures 7 and 8) obtained as the average values for a group of 20 young people between the ages of 15 and 17 conveys a very clear impression of the zone surrounding the head which is "protected by hearing." Figure 7 shows the zone of acoustic protection extending in the horizontal direction, Figure 8 represents the measuring values in an upward and downward direction. The fully drawn lines show the zone of "natural" obstacle sense; the dotted lines represent "technical" obstacle sense (if sonic guiding devices are used).

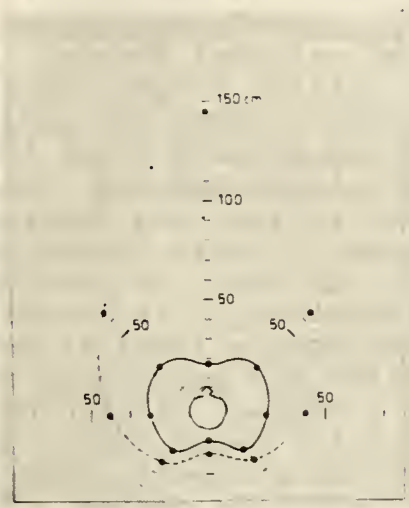

Figure 7. The zone of acoustical protection extending in the horizontal direction.

Figure 8. Measured values in the upward and downward directions.

THE BEST POSSIBLE CONDITIONS FOR ORIENTATION BY SOUND

Thus it is certain that the phenomenon of blind orientation really exists and that it exists also in the case of persons who are in full possession of their eyesight but who had hitherto not found it necessary to make use of this faculty; furthermore it is certain that such indications or clues as make orientation without light possible originate from the ear.

Therefore the question arises as to how this "acoustic alarm system" really works. F. Mansfeld (17), who is himself blind, made a number of useful observations. He distinguishes between "original sounds," i.e., the independent sources by which sounds and noises are excited or produced, and "secondary sounds," by

which he means the resonance of objects which are acoustically irradiated (the usual resonance phenomena), and finally, "return sounds" by which he means the phenomena of sound reflection and echo. Blind persons make use of all three phenomena for purposes of orientation. They derive the most profit from the two first-mentioned phenomena which also supply useful information concerning the *nature* of the object in question. However, the third clue is of equal importance also and will become effective particularly in such cases when obstacles emitting no sound must be detected in a comparatively quiet room.

Reflection and "Shadows" within the Acoustic Zone

The study of acoustics in the usual sense of the word is confined to the science of sound *sources*, i.e., sounds and noises. It is, according to Mansfeld, the science of original sounds. It therefore does not proceed beyond purely initial stages and takes no account of what follows later, once sound waves are present. It is different with light. Only very few objects known to us are self-luminescent. Most of them are illuminated and light is passed on by reflection. Reflection, refraction, diffraction, shadow effect, etc., are more important in this connection than the science of light sources itself. In order to be able to do justice to the problem of blind orientation it is necessary, in an analogous manner, to include also sound *effects* in one's deliberations. Among the latter, reflection and overriding are of importance for the problem at issue. A surface either reflects sound like a "mirror" or it overrides the sound source and throws a "shadow." In both cases an object which itself emits no sound modifies the existing sound and thus attracts notice. The following experiment reveals which of these two cases is of greater importance in practice.

If we fill a room with a constant sound and if, in this sound field, we allow test subjects who are blindfolded to move about, these persons will detect such obstacles as have been erected for test purposes by their natural capacity for orientation. If, however, we cause these persons to act as a sound source themselves, orientation will improve by a multiple. Those sounds or noises, therefore, which originate from the test persons themselves are of the greatest importance for orientation by sound. This is in agreement with a practice long known by blind persons, namely that the noises caused by walking, particularly if hobnailed boots are worn, as well as those caused by a walking stick, by speaking, coughing, etc., are particularly useful for the purpose of "illuminating" their surroundings. In China blind persons carry a gong about with them, not only in order to attract other people's attention, but also for the purpose of orientation.

Changes brought about by sound *reflection* are thus the most efficacious clues for the detection of obstacles. Contrary to

what is the case with light, the reflection of sound waves is by no means sharp. Therefore acoustic clues can never have the same efficiency as light. Nevertheless it is worthwhile to become acquainted with the best possible conditions for orientation by means of reflected sound.

The Problem of "Guide Sounds"

If we include under the heading of "guide sounds" all those sounds which, on the occasion of a blind orientation test, emanate from the observer himself and return to him after being reflected by obstacles, we find ourselves faced with the following question: What frequency, composition, and sound volume of the guide sound is the most favorable for the purpose of detecting obstacles with the utmost correctness and reliability?

This question is, above all, a physical one. The only restrictive condition is that we must remain within the range of hearing capacity of the human ear, because to the ear is alotted the task of interpretation. The corresponding physical basic equation (3, p. 117) results in a function for the degree of reflection of a surface (i.e., for the ratio between reflected and impinging energy) in which, besides the nature of the sound-conducting media, the wavelength of the sound used plays an important part. The shorter the wavelength, i.e., the higher the frequency of the guide sound, the stronger will be the reflection. From this it follows that high sounds are more favorable than low ones. Nature itself provides practical examples. Pierce and Griffin (19) succeeded in measuring the guide sounds of bats, which are of the nature of a number of sharp ultrasonic cries within the range of from 30 to 70 kc following one another in quick succession. These cries begin with a ticking sound (audible also to the human ear) but they last only a few thousandths of a second. This succession of cries increases in the vicinity of obstacles up to 50 to 60 cries per second, and in free space it is again reduced to 30 to 20 cries per second. This supersonic echo sounding process enables bats to detect obstacles (such as telegraph wires) with a diameter of as little as 1 mm.

Most probably this discovery was responsible for the fact that in 1940 a series of experiments was started with a view of making use of this or a similar process also for the benefit of blind persons. Devices for blind orientation were constructed which emitted sounds. However, ultrasonics can be utilized as a guide sound only if a suitable and corresponding receiving plant is constructed at the same time, by means of which inaudible high sounds are transformed into audible ones. For our purpose (utilization of the sense of hearing as a receiver) such "fully automatic" aids to orientation are of no importance, all the more because some time ago they were replaced by other devices which gave better results and which used light instead of sound (compare Bergmann [3, p. 509, etc.], N. Sokal [25], Kohler [15]).

The constructions by Twersky (28) and Witcher (31, 32) who used audible guide sounds form a first approximation to natural conditions. In this manner orientation by sound is made "semi-automatic," in that only the observer's natural hearing capacity functions as a receiver. Partly continuous, and partly impulse-emitted sound waves, within the range of from 8 to 12 kc, are used as guide sounds. We see that here also the tendency persists to use high guide sounds.

A few years ago the discovery was made that the aforementioned frequency range and a similar form of impulse is used also by nature, namely as the cry of orientation of a type of oil bird that lives in caves (Steatornis Caripensis). Griffin (11) reports on the results of his expedition to the caves of Guacharos near Caripe, Monagas, Venezuela, and says that these birds are able to fly about in the innermost caves in perfect darkness without colliding with the walls. While doing so they emit short cries the strongest frequency bands of which are between 6 and 10 kc. The average value of 33 separate frequency measurements (recorded on a tape recorder) was near 7.3 kc. Several tests were then made in a darkened room with a number of captured animals. On this occasion it was found that also in this case the birds did not collide with the walls, but they were frequently heard to brush against them with their wings. Small objects, however, like hanging lamp cords, were in no case detected.

This discovery is of particular interest because it shows that frequencies of less than 10 kc are sufficient to facilitate blind orientation even in blind flying. When attempting to utilize this result with respect to human beings, however, great caution is necessary. Oil birds have to protect a much smaller spatial area than human beings. Their sense of hearing, which in the case of most birds agrees with that of (especially young) persons with respect to absolute thresholds, may be especially sensitive to differentiation just at 7 kc (which certainly does not apply in the case of the human ear). Furthermore, we know very little about the reaction time required by the animal to utilize properly the reflected signal. It is therefore necessary in any case to subject the whole process to a thorough test first before judging it to be most useful for blind people.

Obstacle Sense in a Model Test

If the principle is known that forms the basis of a sensorial performance, it is possible to attempt to construct a technical model of the mechanism. Such a model test is the best means of finding out the optimum conditions for the function.

For this purpose we constructed an "artifical blind man" consisting of a doll having the natural size of a test person (see Figure 9). The place of the ears was taken by a microphone which

was connected by way of an amplifier with recording devices. Otherwise, the situation was exactly that of an obstacle sense test as described above. A sound-emitting device was then fastened to the dummy as was done with the guiding device for the blind, but with the difference that now frequency and composition of the guide sound could be systematically varied over a sound generator.

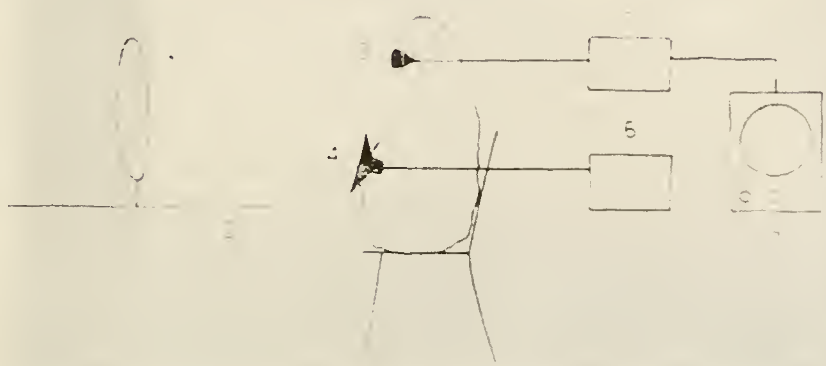

Figure 9. The test situation using an "artificial blind man." The numbers represent the following: (1) the unit obstacle, (2) the rail on which the obstacle is moved, (3) the microphone, (4) a sound-emitting device, (5) an amplifier, (6) a sound generator, and (7) an oscilloscope.

The following "investigations" were then carried out with this construction.

1. Question: What noises are better suited for the detection of obstacles: those which originate from the surroundings or those which originate from the "blind man" himself?

For the investigation of the first part-question a water tap was turned on at some distance from the described device. The test room was filled with the noise made by the running water. Next, the standard obstacle (a round cardboard disk of 50 cm diameter), which was at first placed at a distance of 20 cm from the microphone, was slowly withdrawn on the rail to a distance of 225 cm. The registration device, a cathode ray tube, was at the same time connected with the device in such a manner that the horizontal deviation of the cathode ray in each case corresponded to the distance between the microphone and the obtacle, whereas the vertical deviation was controlled by the sound intensities which happened to occur in the microphone. The photographic picture obtained in this manner of the entire proc-

ess (Figure 10) shows no noticeable change of sound intensity in dependence of the distance to the obstacle. In this case, the artifical "blind man" is indeed blind.

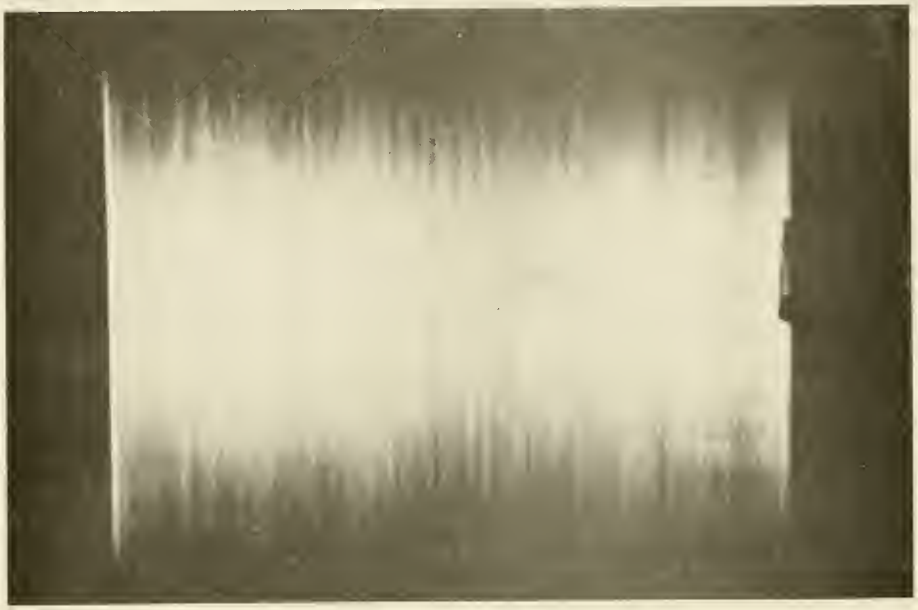

Figure 10. Oscillogram of sound intensity change in the test situation of Figure 9. Note that no noticeable change in sound intensity occurs which is dependent on the distance to the obstacle.

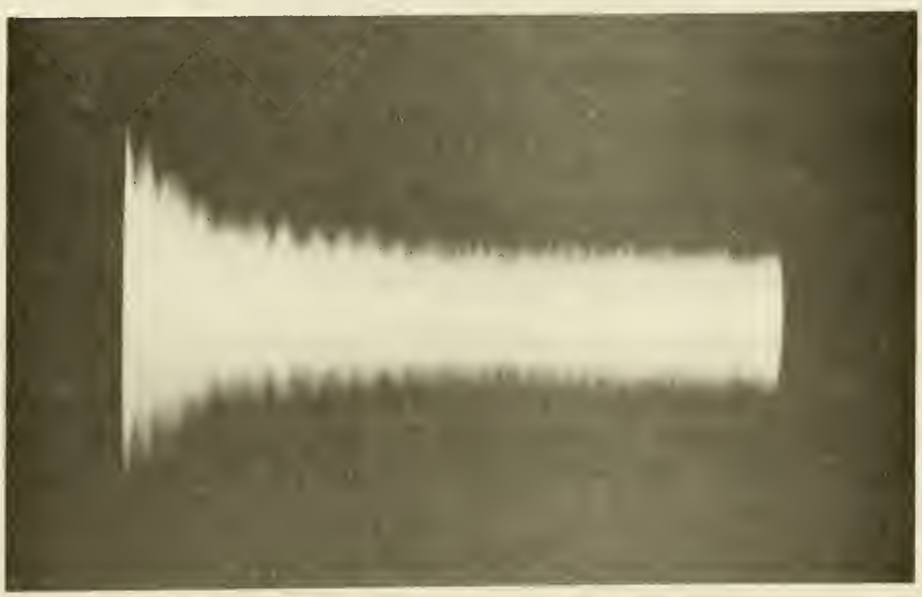

Figure 11. Oscillogram of sound intensity changes in the test conditions of Figure 9 when white noise is emitted by the guiding device. Note that in this case there is a marked change in intensity depending on distance to the obstacle.

Conditions are totally different, however, as soon as similar "white noise" is emitted by the guiding device. Now we find (Figure 11) a distinct change of sound intensity in dependence of the existing distance between the obstacle and the microphone.

The question put above may therefore be answered as follows: Such noises, generated by the blind persons themselves or radiated from a sound emitter placed near the microphone, are by far more effective than noises originating from the surroundings.

2. Question: What sound frequencies are more effective for the detection of obstacles, high ones or low ones?

For this purpose various sine waves were generated with the help of the sound generator and were radiated by the sound emitter. As before, the obstacle was moved from an initial distance of 20 cm up to a distance of 225 cm from the microphone. Figures 12 through 14 show the result for three frequencies, low (50 cycles), middle (1 kc), and high (16 kc).

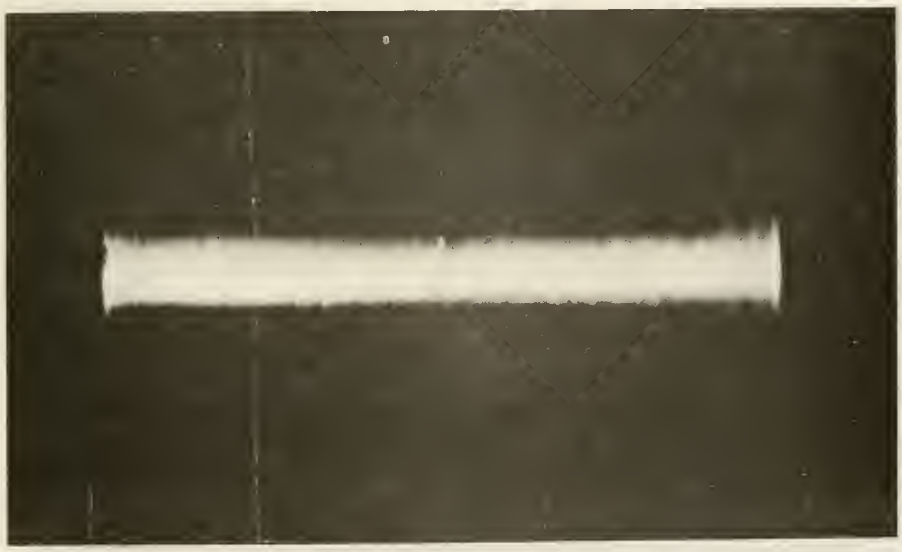

Figure 12. Oscillogram for emission of sine waves of 50 cps under the conditions of Figure 9.

It can be seen at first glance that low frequencies are either not effective at all or only in the immediate vicinity of the obstacle, but that high sounds are effective over greater distances. In addition, the following circumstance may be studied with particular clearness at middle frequencies. It is not possible with the frequencies used to emit sounds in such a manner that only the reflected part returns to the microphone. In spite of all screening devices part of the emitted sound always reaches the microphone directly. Between the latter and that part which is reflected back interferences occur which depend on mutual phase

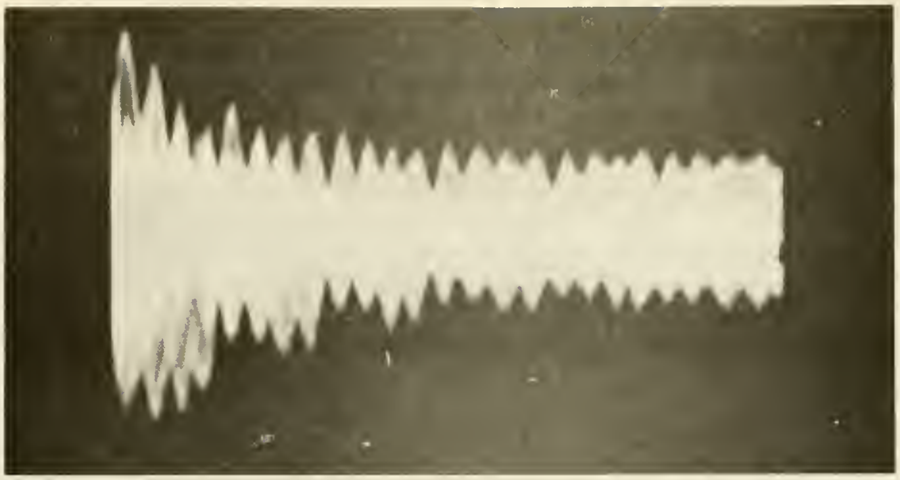

Figure 13. Oscillogram for emission of sine waves of 1 kc/sec under the conditions of Figure 9.

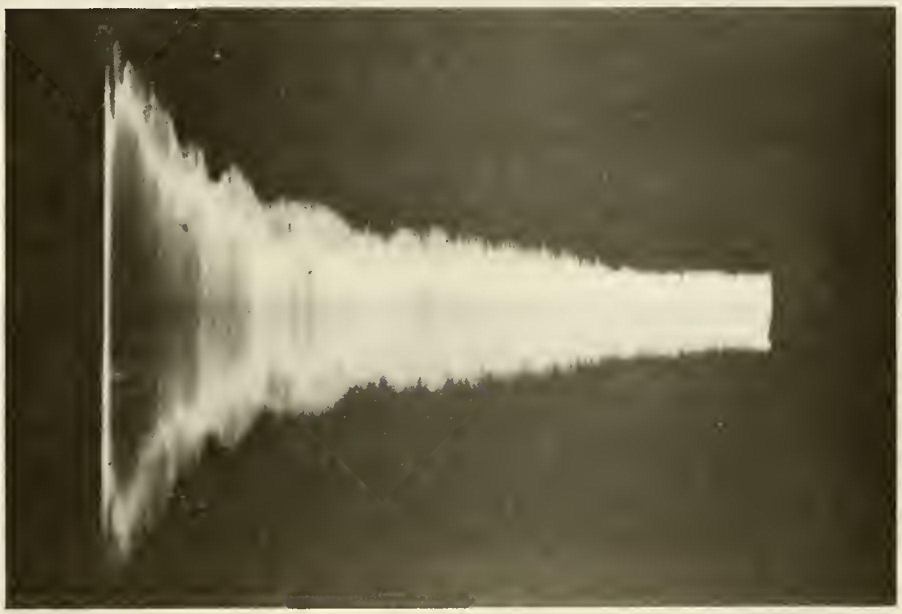

Figure 14. Oscillogram for emission of sine waves of 16 kc/sec under the conditions of Figure 9.

position. These two parts now act either in conjunction, i.e., amplifying each other, or in opposition, i.e., extinguishing each other. This effect is particularly marked as soon as the obstacle is of a size that lies within the range of the wavelength of the guide sound. The contractions shown in Figure 13 are due to this circumstance. If the obstacle is moved away from the microphone at a somewhat greater speed than would be advisable for the purpose of taking a photograph, a distinct "vibration" of the tone

may be heard also by an observer standing nearby.

The answer to the above question therefore is that high frequencies have a longer range of efficiency than low frequencies as regards making reflection surfaces detectable.

3. Question: Are pure tones (sine waves) or sound mixtures to be preferred for the purpose of detecting obstacles; if sound mixtures, then which?

In order to investigate this problem various kinds of sound mixtures were examined by means of the aforementioned device. If, for example, we take a guide sound which contains approximately equal low, middle, and high frequency bands, the result will be the same as if the above-described three frequencies are accentuated; at a greater distance there remain the middle, and then the high frequencies. This, however, means the addition of a new criterion, namely the *composition* of the part which is reflected back in each individual case. Expressed in terms of hearing, this means: the "timbre" of the guide sound changes as soon as the reflecting obstacle surface is offered at verious distances.

Whereas, therefore, the intensity modification of each individual sound frequency is equivocal in itself with respect to distance (a near obstacle that happens to be located in the interference valley produces the same sound intensity at the microphone as a remote obstacle in the case of positive interference), the total result of several frequency bands is composed in a different manner for each and every distance, and this all the more the less harmonically the individual frequency bands are located with respect to one another.

The Illustrations, Figure 15 and Figure 16, were obtained by the use of composed sounds. In the case of Figure 15 a guide sound of 600 cycles with overtones at 1200, 1800, etc., to 12,000 cycles was radiated. In the case of Figure 16 the sound emitter was fed by several current pulses in quick succession, which became audible as "cracks" or "clicks" with a very complicated composition of sound (basic frequency about 2 kc). In both cases we obtain the image of a longitudinal funnel with different compositions of the individual cross-sections (the latter result is not so visible, as the cathode ray must be made very bright in the interest of the photograph and this is bound to lead to a certain lack of fineness of the picture).

The answer to the above question therefore is: Composed guide sounds are more advantageous than pure sine waves. They are reflected by the obstacle in a manner that differs according to frequency, which leads to a modification of the

Figure 15. Oscillogram for emission of mixed sound of 600 cps with overtones at 1200, 1800, etc. cps to 12 kc/sec under the conditions of Figure 9.

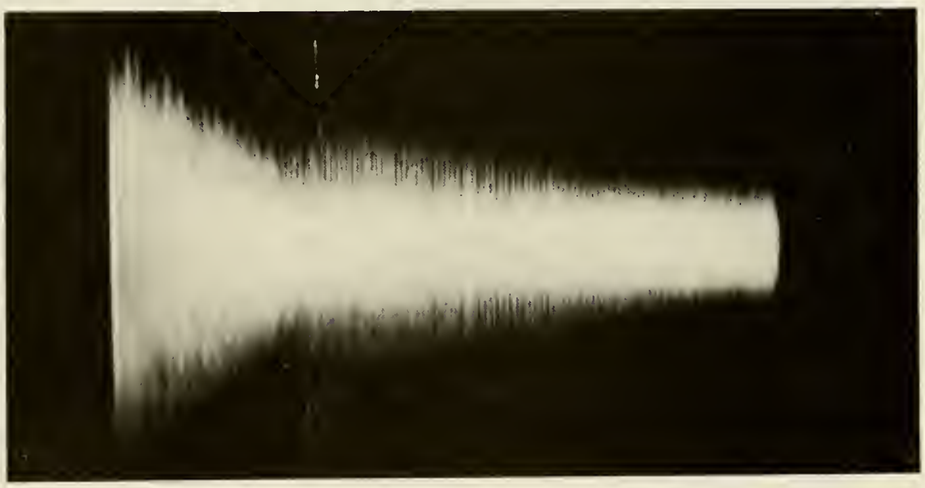

Figure 16. Oscillogram for emission of pulsed sounds with a complicated sound composition (fundamental frequency 2000 cps) under the conditions of Figure 9.

character of the timbre of the entire sound mixture.

4. Question: Hitherto investigation was carried out with "ideal conditions," i.e., the obstacle surface was vertical to the observer. What happens if the surfaces of the obstacle are oblique with respect to the observer? In practice this is most often the case.

A slight modification of the above-described device makes it possible to answer this question also. The unit obstacle was placed for this purpose at a certain distance (50 cm) from the microphone, but it was made to rotate around the vertical axis. What happens if the surface of the obstacle is no longer directed towards the microphone "exactly like a mirror," but forms an angle to it?

Figure 17 shows the measured result and at the same time supplies the answer: the lower the frequency of the guide sound, the more oblique may the surface of the obstacle be placed so that part of the sound is reflected back to the observer. In this case low frequencies are doubtless of advantage.

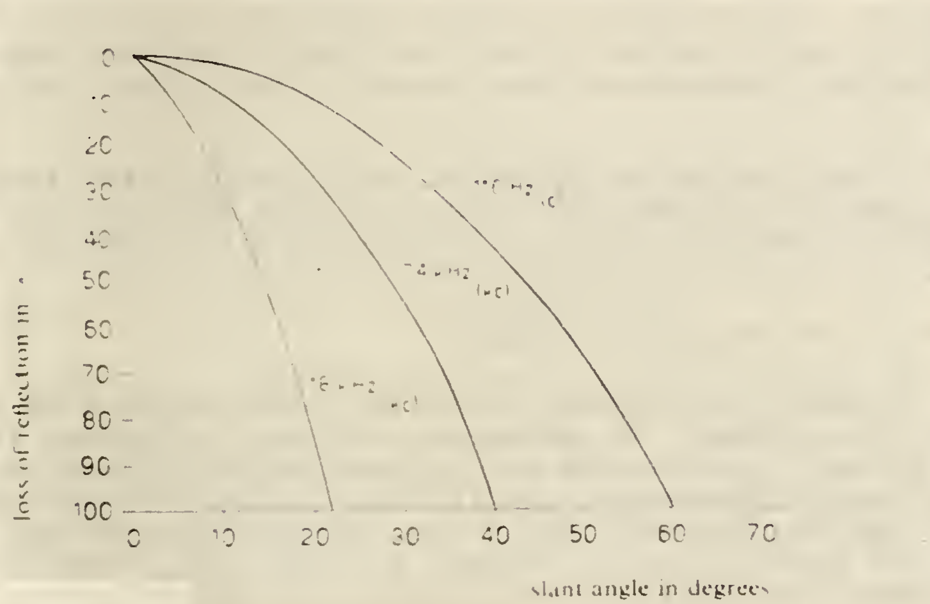

Figure 17. Loss in reflected sound energy as a function of frequency and slant angle of reflecting surface.

From the above-mentioned investigations there thus arises the demand that *composed* sound mixtures which contain both high and low frequency bands be used as guide sounds. Further problems as to the most favorable mode of operation (continuous or pulsed emission), and the most favorable sound volume must be investigated on the occasion of application to practice. Much depends on the human ear with respect to sensitivity to differentiation for sound intensity, pitch, etc., with respect to the capacity of differentiation among surrounding noises, and certainly with regard to separation in time in the case of short impulses following one another in quick succession, etc. Most probably blind flying animals are superior to humans in just

this particular respect, for they are able to differentiate sufficiently well at high frequencies which, among other things, enables them to utilize the Doppler effect as an acoustic clue during flight in the event of approaching obstacles.

ORIENTATION BY SOUND AND SENSE OF HEARING

The physical postulates for the ideal guiding sound will remain "theoretical" as long as they are not confronted with the peculiarities of human hearing. For example, there is no use employing frequency bands that easily tire the ear or are extinguished as soon as other noises are present, or which lie within a range of insufficient sensitivity to differentiation. In short, the attempt must be made to bring about the "best possible compromise" between technical demands and the possibilities offered by the human ear.

Some of the quantities concerned are already sufficiently well known, and with respect to others we have made an attempt to become acquainted with them by checking their practical usefulness.

The Most Favorable Pitch

The limits of human hearing are stated as being between 20 cycles and about 20 kc. Bekesy (2) declares the first mentioned limit to be even below 20 cycles, on which occasion the character of the sound is superimposed with additional sensations such as contact irritation in the ear. Within the range mentioned the finest form of sensitivity is between 1.5 and 3 kc. Within this frequency range the lowest sound energies are sufficient to cause a noticeable aural sensation.

It must be added, however, that this applies only in the case of young persons. If aural capacity at the age of twenty is considered to be the normal standard, a constantly progressing deterioration of hearing capacity may be noticed at first for high and later also for middle sounds. Only the threshold for deepest sounds (up to about 100 cycles) remains constant throughout a person's lifetime. This result is reported by Morgan (18), who also gives exact numerical data which were confirmed by our own research.

This means that with advancing age the deeper components of a guide sound can be better utilized than higher ones. It is therefore of no avail to utilize blindly a frequency range which may be most successful in the case of swallows flying in darkness to humans. In the course of our own investigations we used very complex sound mixtures as guiding sounds in which frequency bands of only a few hundred cycles up to 10 kc occur. This procedure made

it possible for every wearer of such a sonic guide device to "select" the frequency that was most favorable for him.

Guiding Sound or Guiding Impulse?

While measuring hearing capacity it may be noticed that sounds of longer duration show a tendency toward fading. A fact that is particularly noticeable in the case of high sounds. Rosenblith and Miller (22) were, for example, able to state that the threshold for a sound of 4 kc may deteriorate down to 20 db if it is continuous. If, on the other hand, it is divided into a number of individual bursts, sensitivity (and sensitivity for differentiation) will increase. Thus, Bronstein (4) was able to show that a single sound impulse appears subjectively to be louder if shortly before another impulse has been heard, than if it is alone. Shower and Biddulph (24) found, when measuring the sensitivity to differentiation for pitch, that the best results can be obtained if sounds used for comparison are allowed to alternate about twice per second. A similar result was obtained by Rawdon-Smith and Grindly (21) with respect to the capacity of differentiation for sound volume. Sound *impulses* are therefore more favorable in a fundamental respect than continuous sound.

In practical orientation tests these results were immediately confirmed as soon as test subjects were allowed to choose between continuous sounds and impulses. Continuous sounds are rejected as being disagreeable or troublesome. If the subject is offered the possibility of interrupting the guiding sound at his discretion by pressing a button, the most agreeable impulse frequency is in all cases obtained at 4 to 6 sound bursts per second.

Furthermore it must be added that the use of sound impulses is advantageous in another respect. If, for example, we approach a wall with a "clicker," (i.e., a device that emits short and sharp "clicking" sounds) the first thing we hear is the echo of the radiated impulses. This is an important indication just for such objects as are located at a greater distance. When using continuous sounds we find that this indication or clue is lost or is replaced by interference fluctuations which, however, are subjectively less marked.

If we move still closer to the wall, the intermediate intervals between impulse and impulse echo become smaller and smaller. Under a limit of 3 m the two impulses, however, begin to amalgamate into one. The reason is, on the one hand, again one of the limits of human hearing for the separate perception of sound pulses which follow one another in quick

succession. On the basis of a value of from 2 to 3 msec it is found by computation that below 90 cm no differentiation between impulse and impulse echo is possible. In addition to this there is, on the other hand, the duration of the sound impulse used in each case. Here there is a limit, this time a technical one; it is not very well possible to radiate impulses of any shortness. Every oscillating system (but particularly loudspeakers available on the market) dies down and therefore radiates acoustic stimuli during a longer period of time, even if it has been struck only quite shortly. If, however, the sound impulse lasts several hundredths of a second, impulse and impulse echo amalgamate some meters before the obstacle.

In this respect bats and oil birds are superior because the length of their cries of orientation is within the range of a few milliseconds. It would not be of much avail, however, were it possible to bring the guide impulses for human orientation up to this level for then other difficulties are bound to occur. The human ear has its limitations with respect to sounds of any shortness. Below a duration of two-tenths of a second it is not yet able to develop a tone and remains a click. For a click, on the other hand, it is true that its loudness decreases rapidly with increasing shortness, although its amplitude remains exactly the same. Also sensitivity to differentiation fails in the case of such "undeveloped" sounds: the click of longer duration becomes the click of greater loudness, etc. (16, pp. 1020-1024).

On the Question of the Sensitivity to Differentiation of the Human Ear

In the course of our investigations we came to the conclusion that it is upon this that the entire problem is based. Only little influence is exercised on the efficiency of orientation by sound by whether a person's hearing is particularly fine or not (measured in values of absolute sound thresholds*). On the other hand it is of the greatest importance to what extent a person is able to detect *modifications* of sound (the problem of differential thresholds). The following observations and results have influenced our opinion in this respect:

1) We not unfrequently found ourselves faced by the fact that subjects whose hearing was below the average (referred to

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*The term "absolute threshold" refers to the lowest stimulus threshold, i.e., that intensity of stimulus which is still able to cause a sensation. The differential threshold, however, refers to the additional stimulus which is necessary to cause a just noticeable modification of an already existing sensation.

the average values of our audiometer measurements) nevertheless develop an obstacle sense that is above the average. This was particularly marked in the case of blind subjects of advanced age.

If we proceed from the fact that the faculty of blind orientation is connected as a condition sine qua non with the ear (see the above-mentioned results, obtained in the course of experiments carried out with deaf-blind and deaf persons) we find ourselves faced by a mystery - but only as long as it has not yet been made clear that the term "hearing capacity" is very vague indeed; it may cover two different separate faculties which need not necessarily coincide in all cases, e.g., absolute sensitivity and sensitivity to differentiation.

2) We were not less surprised by the results obtained by calculating the correlation between results of audiometer readings and obstacle sense capacity. If a "fine ear" were a necessary condition for a "good obstacle sense," this would manifest itself by a high positive correlation coefficient between these two faculties. Computation, however, resulted in the low value of from .20 to .40 (the slight increase occurs near the frequencies between 1 kc and 8 kc).

3) Similar surprise was caused by the result of computing the correlation between the age of the subjects and obstacle sense performance. Also in this case a value of -.30 was attained. This result shows that apparently not the absolute thresholds but some other part-faculty of the sense of hearing is of greater importance for good obstacle sense.

4) A corresponding result was obtained also by the training courses for obstacle sense (described below). Among individuals whose hearing was equally good (measured in values of absolute threshold) by no means all were able to attain the same level of performance with respect to blind orientation. Only a small percentage (numerically expressed about 2.6 percent of the population) can be trained to a level that is high above the average, whereas the others, in spite of the fact that they all show the same good will and are equally well trained, will never surpass the normal or average level of performance. They seem to lack a certain inherent quality which, though connected with their sense of hearing (if the ears are stopped up there is no obstacle sense), has no connection whatever with the absolute thresholds.

Unfortunately very few investigations have hitherto been carried out, as far as we know, concerning the correlation between absolute thresholds and differential thresholds of hearing, particularly with respect to age and the deterioration of

hearing usually connected therewith, but it has been established that these two part-faculties may diverge completely in extreme cases. The problem of "recruitment" which forms the subject of frequent discussions nowadays (deterioration of absolute thresholds in the case of intact or even considerably increased thresholds for alteration of sound) serves as an example in this case.

From all that has been said it follows - as will be found by an exact analysis of the situation - that in orientation with the aid of sound, the faculty of differentiation is more important than the fineness of absolute thresholds.

5) On the basis of these considerations it seemed to be necessary to verify the hypothesis: a good ear for sound *modifications* is of essential importance for obstacle sense performance. We constructed a sound modifier on the principle of a rotating surface within a constant sound field. The nearer the sound emitter is to the rotating surface the greater will fluctuations become.

The illustrations, Figures 18 and 19, show this device as well as some of the results obtained. From a sound emitter (miniature earphones with trumptet, white arrow on the right) a constant hissing noise with an intensity of about 30 db was emitted. Immediately to the left (marked by a curved arrow) is the rotating surface covered by a round piece of cardboard. In a forward direction sound is able to pass from the box, the walls of which are covered with cotton wool, through an opening. (For better illustration the lid is shown opened.) In order to be able to vary the intensity of sound fluctuations the sound emitter is movable, and by pressing a button the test subject was able to move it upwards (thus removing it from the rotating surface and away from the range of sound fluctuations), or back to initial position (downward direction). The motions of the sound emitter from "just still noticeable" to the "just no longer noticeable" range of sound fluctuations and back were automatically recorded.

In this way the "curves" shown in Figure 19 were produced. The lower and upper turning points indicate in each case when the subject believed he was just again able to hear or just no longer able to hear the fluctuations of sound. The subject was instructed to reverse the direction of the sound emitter by pressing the button just at these moments. The experiment in each case lasted 3 minutes. The example shown on the left concerns a test person whose hearing was good, but, as can be seen, with a peculiarly delayed reaction to whether the sound was fluctuating or not. Therefore there are few large zags within the test time available. This test person has an obstacle sense of 90 cm (measured by the apparatus described above). The middle and right

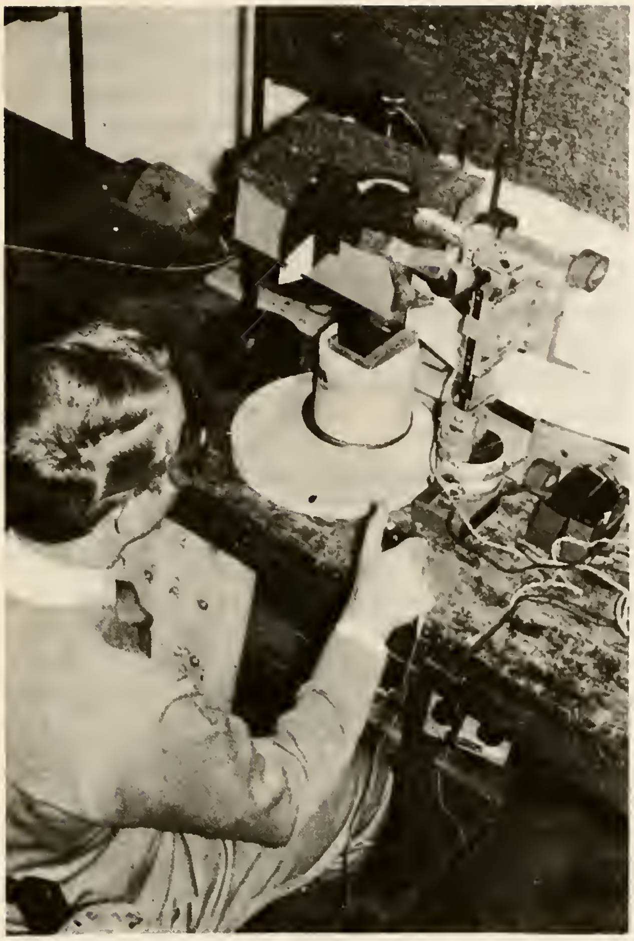

Figure 18. A sound modifier operating on the principle of a rotating surface within a constant sound field.

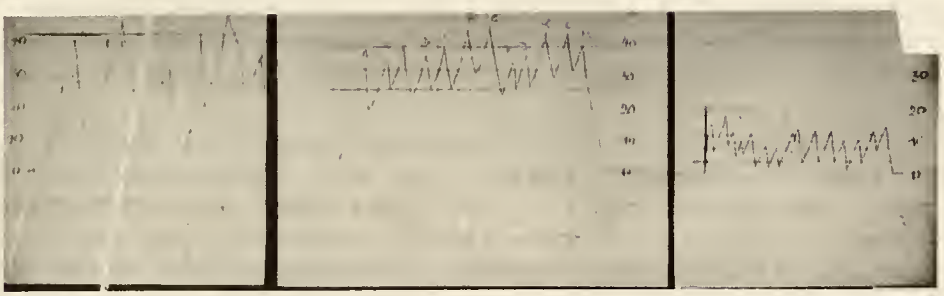

Figure 19. Lower and upper turning points for test subjects: (left) good hearing ability but with markedly delayed reactions to variations in sound; (middle) good hearing ability combined with precise reactions; (right) poor hearing ability in spite of an extremely acute detection of the finest variations in sound; a significant relation exists between the latter ability and a good performance in obstacle detection (see text).

curve pictures are from test persons with good (130 cm) and extremely good (210 cm) obstacle sense. In the latter examples reactions follow one another in rapid succession. The example on the right is very informative because it shows that in spite of a low absolute hearing capacity (that is why the entire curve is within the "safe" range) there is nevertheless a fine differentiating capacity for modifications.

Computations of the results obtained from 48 persons resulted in a correlation of +.74 between fine and rapid reactions on the aforementioned sound modifier and obstacle sense performance. (Static values: $t=7.31$, corresponding P-values of the t-function: $P_{.05}=2.014$, $P_{.01}=2.689$, $P_{.001}=3.521$.)

It is thus not important to find out whether a sound exists or is lacking, but to determine the variations of this sound. For the latter purpose, however, fineness of differentiation thresholds is essential. At normal walking speed this concerns mainly intensity fluctuations of sound or of individual sound components and their mutual relations.

The sensitivity to differentiation for an increase of sound volume is obtained in the finest degree for an average range of pitch between 1 kc and 4 kc. Within this range there is the largest number of discernible stages of intensity (according to Fletcher, cited from Scheminzky [23, pp. 197-198]). Within the same range also the capacity for differentiating between fluctuations of pitch is finest (in the case of a standard sound of 1000 cycles an increase of 3 cycles is sufficient). Conditions, however, become complicated because the differential threshold always depnds on both, i.e., on the pitch as well as on the sound volume of the sound investigated; in this connection please compare three-dimensional representations (frequency, volume, and increment) by Licklider on the basis of measurements carried out by Riesz as well as by Shower and Biddulph (16, pp. 999-1000).

For our purposes it may be gathered that guiding sounds within the range of between 1 and 4 kc are most effective for the human ear, as corresponding modifications in perception occur on the occasion of the smallest modifications of stimuli within this range only. The necessary compromise between pitch and sensitivity to differentiation must therefore be transferred to this range.

A further important point is the differentiating capacity for sound compositions (timbre). The timbre of a tone depends on the manner and the intensity of its overtones. Pure sine oscillations sound soft, and if harmonic overtones are added, the character of the sound becomes fuller or rougher according to whether the even- or the odd-number octaves predominate. Non-

harmonic overtones such as happen to occur particularly in connection with short sound pulses make the sound hard and metallic. These are results which have been known since Helmholtz and Stumpf. Further and more extensive investigations, particularly with respect to the differentiating sensitivity for timbres in the case of the very smallest modifications of the volume of part-tones within a given sound mixture, have as far as we know not been carried out.

Observations which we have made in the course of our orientation training carried out with the aid of the "clicker" suggest, however, that this value must be very low. The detection of obstacles is based mainly on perceiving a modification of the sound made by the click. The sound suddenly appears to be harder, or also higher, as many test subjects declare who are not so well trained in analyzing their own aural sensations. What changes physically at the approach of a reflecting obstacle surface is, at first, only the sound volume of the high partial sounds, and later also the medium and low sounds. This is at first felt as a modification of timbre and only later as a general increase of intensity.

The Part Played by Surrounding Noises

Since 1920 numerous investigations of the so-called "masking effect" have been made. This is the property of a given sound of making other sounds occurring simultaneously inaudible. It is of importance to take these results into account in order to avoid selecting a guide sound that is easily "covered" by other noises (particularly those occurring in the immediate surroundings).

Wegel and Lane (29) proved that high sounds are much more easily covered by deep sounds than vice versa. This means that the choice of a single high guide sound is surely disadvantageous as it would soon be masked by surrounding noises. Furthermore, it was found that sounds (and tone components) of similar frequency are more easily covered than those of dissimilar frequencies.

With respect to the masking effect it appears therefore that clicks with differently developed frequency bands, in which low frequencies should occur, are the most favorable choice for a guide sound.

Finally, there is one property of the human ear as a "biological organ" which renders it much superior to all apparatus and devices. A noise or a signal that can at first be only very indistinctly distinguished from surrounding noises is perceived with progressively improved result the longer the

person is trained in doing this. This capacity has already been closely investigated in connection with listening to morse signs or talking against a powerful acoustically disturbing background as for instance the noise made by an airplane (Egan [8]). This is part of the general ability to distinguish individually nearly any kind of components in composed acoustic stimuli by directing one's attention and practice. Nevertheless, such components will be selected in the interest of the best possible differentiation as could more easily be distinguished before undergoing any training, and in our case these are above all characteristic composed click-like guide sounds.

PRACTICAL APPLICATION

Our way is now sketched out. It leads via the guiding device to training of orientation. Guiding devices which satisfy the demands made are constructed in the most simple manner by relay circuits which charge a storage condenser when at rest, and which discharge it again when in operating position. Charging and discharging takes place in form of a short circuit by way of the loudspeaker so that a distinctly audible click is produced. By resistances which limit the current, and by additional condensers which filter out the higher frequencies, a series of clicks are produced which best satisfy the demands made as to frequency bands, sound intensity (to be regulated according to the level of surroundings), etc. Beyond this, practical application provided further indications as to the best way to carry the device, the manner and form of sound projection, etc.

Whereas, for example, Twersky and Witcher (28, 31, 32) are in favor of the guiding device being carried in the person's hand in order that it may be used somewhat in the manner of a pocket torch to determine the direction of the object sought, we found that this method produces satisfactory results only in the case of high guiding sounds. In this case emission can, if further assisted by a parabolic mirror in the center of which the real sound emitter is located, be actually bundled so sharply that no part of the sound any longer immediately reaches the ear of the wearer of the device, so that he orientates himself solely by echoes.

Here it is actually the absolute hearing threshold that is of importance. Control tests subsequently carried out by us showed, however, that this method is of doubtful value because of the always present surrounding noises. The absolute threshold for high sounds, which is in any case rather roughly definable (e.g., at more than 13 kc) deteriorates considerably if disturbing noises are added. However, as soon as lower frequency bands are used at the same time part of the sound always reaches the ear of the wearer directly; this is, then, the cause of uncontrollable modi-

fications of sound which, if the device is in motion while being carried, are caused by the ever-changing distance between it and the ear. It was therefore necessary, in order to eliminate this disturbing "melody of walking," to fasten the device firmly to the wearer's chest (immediately below the throat). We found further that this location is the most favorable also in other respects. If, for instance, the sound emitter is attached to the wearer's head, the emitted signal no longer suffices to make the obstacles near the ground detectable. Sound modulation is then too low because of the great distance between sound emitter and reflecting surface. If the device is moved nearer the wearer's feet the region surrounding the head loses its protection, and besides, the skin sensations (mentioned briefly at the very beginning) do not occur, sensations which are felt not only by blind persons but also by blindfolded persons after some practice, and which play an important part as alarm sensations. (The connection with skin sensations is explained elsewhere.)

Figure 20. Use of the sonic guiding device worn by a subject (center). The oscillogram at the left shows a single sound impulse with a basic frequency of 400 cps. The obstacle training course used in the tests is shown in the background.

Figure 20 (a composed photograph) shows in the foreground one of our test persons wearing the sonic guiding device. On the left, the character of a single sound impulse is shown in the oscillogram; these pulses follow one another every two-tenths of a second. The jags on the lower edge of the picture

indicate interval distances of one-hundredth part of a second each. It may be seen that the basic oscillation of the impulse is near 400 cycles. Overtones are, as was shown by frequency analysis, at about 2.8 and 11.5 kc. The sound volume of the pulses, each of which lasts about one-tenth of a second (and sounds like buzzing) corresponds to usage when the device is tuned down for use in rooms to about 30 db (at a distance of 30 cm from the sound source); when tuned to full volume, it corresponds to double this amount.

Training of Orientation (Obstacle Sense School)

On the basis of the described investigations the following two questions may be put forward for the purpose of evaluation, and answered: what performance may be attained in practice with the help of such a sonic guide device; and whether by such training natural capacity for orientation (without technical aid) may be improved?

The first question gives rise to the following seemingly contradictory statement. The same subjects who, when obstacle sense was measured, attained values of more than 1.60 m, attained hardly 1 m when *actively approaching* an obstacle of the same standard size (50 cm in diameter). A closer analysis of the situation soon provided the answer.

When measuring the obstacle sense the obstacle is introduced into the sound cone of the guiding device from above (in order that no draught be caused). Modification of sound (by reflection) therefore occurs much more quickly than in the case of a gradual approach to an obstacle while walking. In the latter case the stimulus or the modification of the stimulus "creeps in." Therefore, according to an old law of perception, the result is a marked coarsening of the sensitivity to differentiation and, as a result, a deterioration of performance. In addition, and this is also a fact known from psychophysics, a modification of stimulus coming from the range below threshold and being displaced towards the threshold is detected later than in the reverse case. It is just such situations (approach from the undiscernible to the discernible range of an obstacle) that are, however, the rule in practice.

We have directed our special attention to this point in training tests. At first we put the question whether an alarm sounded at a distance of 50 cm from the obstacle is at all sufficient in order to be able to avoid an obstacle (at normal speed of walking). This is indeed the case (alarm was given by calling to the person concerned). In practice, however, conditions are

more favorable as obstacles are larger than our standard plate. In these cases, and above all outdoors, as for example opposite walls, protruding corners, and stairs leading upwards, fences, etc., the range of discernibleness is in general far above 50 cm.

In addition to this, improvement is attained as the result of systematic training. Training itself was carried out in such a manner that each test person had to perform a number of tasks of increasing difficulty: walking towards a wall; against cardboard obstacles of various sizes and heights; detection of protruding and receding corners; walking at constantly equal distances from walls or walking in the middle of natural or artificial corridors; finding one's way out of labyrinths; distinguishing between "wall," "window" (open and closed), "door," "person," "tree," etc.; detection of low obstacles; walking during noise; etc.

We were somewhat sceptical about the last-named tasks, and indeed it is here that we found the limit set to the entire procedure. Low obstacles not reaching up to a person's knee which are also rather narrow are usually undetectable. To find them it will be necessary, as before, to make use of a stick. Obstacles that are narrower than 5 cm, e.g., a single wooden plank, iron rods (not arranged in form of a lattice), can also not be detected in time. Furthermore, obstacles often reach the limit of detectability if they are both narrow and sound-absorbing, as e.g., pedestrians standing without moving with their shoulders pointing in the direction of the observer. Noise produced during training also plays an important part. For test purposes we used tape records of machine-room noise which were played at various degrees of loudness. The values ascertained with 20 subjects were as follows. In the case of disturbing noise of about 50 db the capacity of detecting obstacles while walking about freely is reduced by 21 percent; at 100 db by 80 percent. In crowded streets with much traffic (from about 70 to 80 db upwards) sufficient orientation can not be assured. It would, of course, be possible to amplify the guiding sound in such situations, but this can hardly be considered to be a serviceable method in the interest of other users of the road.

In the case of "exceptional" conditions (and by this we mean walking during a storm, in rain, snow, off the beaten track, or at high altitudes), the efficiency of blind orientation changes according to the changes in sound conditions. This efficiency suffers most by storm because of the loud noises caused by wind in the ear (cf. what has been said above about the "masking effect") and also by heavy rain, and, lastly, by newly fallen snow (by a decrease of reflection). Efficiency

of blind orientation is, however, improved at higher altitudes; here conditions become similar to what has been said in connection with sound-proof cells. In pathless territory, as when walking through a (not too dense) forest, it is possible to avoid coming into collision with trunks of trees, brushwood, slopes, etc., but it is not possible to keep walking in one direction, i.e., to cross the entire forest simply with the aid of blind orientation.

Apart from these limits training carried out on playgrounds (see background of Figure 20) as well as in suitably chosen situations of everyday life has shown that sufficient orientation is possible and can be attained - orientation which corresponds to about three times better than the natural performance of well-trained blind people. A particularly important part is played in this connection by the increase in performance by training itself. Figure 21 in diagram form shows the combined result of two training groups with a total of 40 subjects during a period of 6 weeks (18 to 20 hours of training per person). In certain intervals before, during, and at the end of training the distance was measured from which a unit obstacle (of 50 cm) was just still detectable. The dotted line shows these measuring results when a relay clicker was used; the solid line shows results of a test without the use of the sonic guide device.

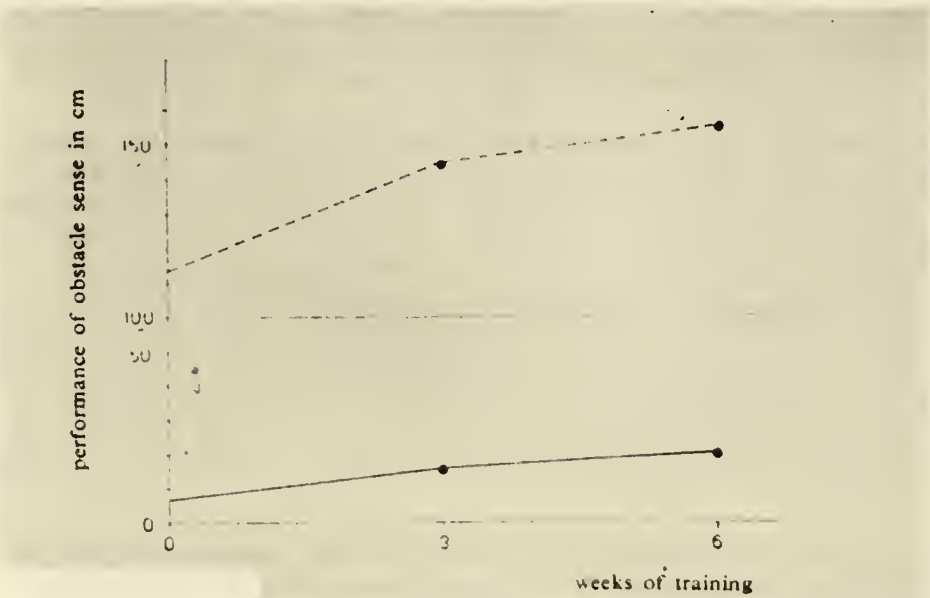

Figure 21. Improvement in detection of obstacles after training of the obstacle sense. The solid line shows improvement without the use of the guiding device; the dotted line shows improvement using a relay clicker.

A control group of persons who underwent such a course of training without a sonic guide device showed no significant improvement of performance.

SUMMARY AND REVIEW

The sense of hearing is the basis of the peculiar ability involving orientation without light (avoidance of obstacles) which is known as "obstacle sense of the blind." Methods of investigation were developed which permit measuring the obstacle sense. As a result of measurements undertaken with a large number of subjects it was found that one-third of them possessed this ability. In most cases they knew nothing about this beforehand (with the exception of blind subjects) and, being able to see, they did not depend on it.

The "mechanism" of obstacle sense, it was further found, is based upon the exploitation of *modifications* of sound which are produced by reflection on near obstacles. In this connection that sound which is emitted from the observer himself is found to be the more effective.

In imitation of biological (bats, oil birds) as well as of technical examples for orientation by sound, sonic guiding devices were developed which take both the technical demands to be made and the peculiarities of the human ear into account. With their aid it was possible to extend the "acoustic protective zone" over such a range that independent orientation at home and in the streets is, in principle, possible.

At the same time also the limitations of this method are revealed. On the one hand, they are caused by our absolute and differentiation thresholds for sound and sound modification, and on the other hand, physically, by the unfavorable ratio between the wavelengths of sounds and the sizes of the objects. The wavelength of audible sound is too large in comparison with surfaces so that a sharply defined "image" is not possible. Echolocation by the human ear in general suffices only for the purpose of ascertaining the *existence* of an obstacle without, however, imparting any further information as to its "shape," that is to say its sharp outlines.

In any case, training courses (the "obstacle sense school") have shown that additional results may be obtained by training. The ear can prove its analytical ability to discern the essential modifications of sound with ever-growing success, from the noise level prevailing at the time, and of combining them with the forward motion of the body so that at least roughly detailed "stage scenery" is created (a wall interrrupted by an entrance door, an open window, an arched doorway, a tree, etc.).

Beyond that, measurement results of the "pure" obstacle sense improves in the course of such training which means that the acoustic zone of protection around the head becomes enlarged.

The practical importance of the method probably is the following: by means of training, with the help of a sonic guiding device, the natural obstacle sense capacity is awakened and developed to maximum efficiency. Not only blind persons trained in this manner, but also blindfolded subjects, can make use of this ability if necessity arises, and will have success where untrained persons will fail.

REFERENCES*

1. Ammons, C. H., P. H. Worchel, and K. M. Dallenbach, "'Facial Vision': The Perception of Obstacles Out of Doors by Blindfolded and Blindfolded-Deafened Subjects," Amer. J. Psychol., Vol. 66 (1953), pp. 519-553.

2. Bekesy, G. von, "Über die Hörschwelle und Fühlgrenze langsamer sinusförmiger Luftdruckschwankungen," Ann. Physik., Vol. 26 (1936b), pp. 554-566.

3. Bergmann, L. Der Ultraschall und seine Anwendung in Wissenschaft und Technik (5 Aufl.). Zürich, 1949.

*4 Bronstein, A. J., "Sensibilization of the Auditory Organ by Acoustic Stimuli," Bull. Biol. Med. Exp. (URSS), (1936), pp. 274-277, and 347-349.

5. Cotzin, M., and K. M. Dallenbach, "The Role of Pitch and Loudness in the Perception of Obstacles by the Blind," Amer. J. Psychol., Vol. 63 (1950), pp. 485-515.

*6. De Vries, H., "The Minimum Audible Energy," Acta Oto-laryng. (Stockholm), Vol. 36 (1948), pp. 230-235.

7. Dolanski, Wl., "Les Aveugles possedent-ils le 'Sens des Obstacles'?" L'Annee Psychol., Vol. 31, No. 1 (1931).

*8 Egan, J. P., "Articulation Testing Methods," Laryngoscope, Vol. 58 (1948a), pp. 955-991.

*The articles marked by a star were not submitted in the original. Data were obtained from text books which contain a short summary of the contents of the aforementioned articles. These text books are the unnumbered listings at the conclusion of the references.

9. Erismann, Th., and I. Kohler, Warnung im Dunkeln, (Forschungsfilm über den Fernsinn der Blinden). Innsbruck, Austria: Filmproduktion Pacher & Peithner, 1953.

*10. Griffin, D. R., "How Bats Guide their Flight by Supersonic Echoes," Amer. J. Physiol., Vol. 12 (1944), p. 342.

11. Griffin, D. E., "Acoustic Orientation in the Oil Bird (Steatornis)," Nat. Acad. Sci., Vol. 39, No. 8 (1953), pp. 884-893.

12. Griffin, D. R. and R. Galambos, "The Sensory Basis of Obstacle Avoidance by Flying Bats," J. Exp. Zool., Vol. 86 (1941), pp. 481-506.

*13. Jerome, E. A. and H. Proshansky, Blindness: Modern Approaches to the Unseen Environment. Princeton, New Jersey: Princeton University Press, 1950, pp. 462-494.

14. Kohler, I., "Der 'Fernsinn' der Blinden," Die Umschau, (1952), pp. 449-451.

15. Kohler, I., "Die Technik im Dienst des Blinden," Die Pyramide, Vol. 5, No. 6 (1954), pp. 87-93.

16. Licklider, J. C. R., "Basic Correlates of the Auditory Stimulus," in S. S. Stevens (ed), Handbook of Experimental Psychology, New York: John Wiley and Sons, Inc., 1951.

17. Mansfeld, F., "Die Verdunkelung und die Blinden," Arch. f. d. ges. Psychol., Vol. 107 (1941), pp. 411-436.

18. Morgan, C. T. Physiological Psychology. New York: McGraw-Hill, 1943.

19. Pierce, G. W. and D. R. Griffin, "Experimental Determination of Supersonic Notes Emitted by Bats," J. Mammal., Vol. 19 (1938), p. 454.

20. Potuschak, B. M. "Über die Entstehung der Hautempfindungen beim Fernsinn der Blinden." Dissertation an d. Phil. Fak. d. University Innsbruck, 1956.

21. Rawdon-Smith, A. F., and G. C. Grindley, "An Illusion in the Perception of Loudness," Brit. J. Psychol., Vol. 26 (1935), pp. 191-195.

*22. Rosenblith, W. A., and G. A. Miller, "The Threshold of Hearing for Continuous and Interrupted Tones (Rezension)," J. Acoust. Soc. Amer., Vol. 21 (1949), p. 467.

23. Scheminzky, F. Die Welt des Schalles. Verlag Das Bergland-Buch, 1935.

*24. Shower, E. G., and R. Biddulph, "Differential Pitch Sensitivity of the Ear," J. Acoust. Soc. Amer., Vol. 3 (1931), pp. 275-287.

25. Sokal, N. "Guidance Devices for the Blind." Doctor's Thesis, Massachusetts Institute of Technology, 1950.

26. Supa, M., M. Cotzin, and K. M. Dallenbach, "'Facial Vision': the Perception of Obstacles by the Blind," Amer. J. Psychol., Vol. 57 (1944), pp. 133-183.

27. Truschel, L., "Das Problem des sogenannten sechsten Sinnes der Blinden," Arch. f. d. ges. Psychol., Vol. 14 (1909), pp. 133-178.

28. Twersky, V., "Sound Flashlight for the Blind," Electronics, Vol. 21 (1948), pp. 156, 158, 160.

*29. Wegel, R. L., and C. E. Lane, "The Auditory Masking of One Pure Tone by Another and Its Probable Relation to the Dynamics of the Inner Ear," Physiol. Rev., Vol. 23 (1924), pp. 266-285.

30. Winkler, M. "Untersuchungen über den Fernsinn an einer Blinden Katze." Dissertation an d. Phil. Fak. d. University Innsbruck, 1953.

31. Witcher, C. M., "Pulsed Sonic Beam Obstacle Detector for the Blind," Radio News (Radio-Electronic Eng. Edition), Vol. 9 (1947), p. 8.

32. Witcher, C. M., "Echolocation for the Blind," Electronics, Vol. 27, Dec. 1954.

33. Worchel, P., and K. M. Dallenbach, "'Facial Vision': Perception of Obstacles by the Deaf-Blind," Amer J. Psychol., Vol. 60 (1947), pp. 502-553.

34. Worchel, P., and J. H. Berry, "The Perception of Obstacles by the Deaf," J. Exp. Psychol., Vol. 43 (1952), pp. 187-194.

35. Young, P. T., "Auditory Localization with Acoustical Transposition of the Ears," J. Exp. Psychol., Vol. 11 (1928), pp. 399-429.

Bekesy, G. von, and W. A. Rosenblith, "The Mechanical Properties of the Ear," in S. S. Stevens (ed), Handbook of Experimental Psychology. New York: John Wiley and Sons, Inc., 1951, pp. 1075-1115.

Hallowell, D., "Psychophysiology of Hearing and Deafness," in S. S. Stevens (ed), Handbook of Experimental Psychology. New York: John Wiley and Sons, Inc., 1951, pp. 1116-1142.

Licklider, J. C. R., "Basic Correlates of the Auditory Stimulus," in S. S. Stevens (ed), Handbook of Experimental Psychology. New York: John Wiley and Sons, Inc., 1951, pp. 985-1039.

Licklider, J. C. R., and G. A. Miller, "The Perception of Speech," in S. S. Stevens (ed), Handbook of Experimental Psychology. New York: John Wiley and Sons, Inc., 1951, pp. 1040-1074.

Stagner, R., and T. F. Karowski. Psychology. New York: McGraw-Hill, 1952.

Woodworth, R. S., and H. Schlossberg. Experimental Psychology. New York: Holt, 1954.

SONAR SYSTEM OF THE BLIND*

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INTRODUCTION

One of the most remarkable discoveries of modern times has been the development of long-range scanning devices like radar and sonar. The Air Force and the Navy, as constituted today, could not exist without them. By electronically analyzing the echoes which are bounced off of objects in the sky (radar) or from objects in the ocean ("active" sonar), the location, movement, and characteristics of these objects can be determined. Although the basic principle of reflected echoes is the same for both, radar makes use of radio echoes and sonar of sonic or ultrasonic echoes. The development of sonar (*so*und *na*vigation *r*anging) was necessitated by the fact that radar (*ra*dio *d*etecting *a*nd *r*anging) will not work beneath the surface of the water.

Today, all large vessels and many smaller ones are equipped with echo sounders or fathometers which beam sonar pulses downward to measure the depth of the water beneath the hull. The echo sounder thus takes the place of the sounding lead. Commercial fishermen locate schools of fishes by the ultrasonic vibrations which are reflected from the fishes' bodies. A submarine navigating beneath the polar ice cap determines by sonar not only (i) the distance and contour of the bottom but also (ii) the amount of free water between the top of the vessel and the ice above it and (iii) the presence of reefs, submerged mountains, or other obstacles in a horizontal plane.

ECHO RANGING IN ANIMALS

But these electronic marvels of radar and sonar are matched or even surpassed by the echo ranging or sonic perception of such animals as the bat and the bottlenose dolphin or porpoise. Bats catch night-flying insects on the wing by listening to the echoes of their own rapidly repeated cries (1). This unique method of distance perception in the bat was originally discovered by Spallanzani as far back as 1793 (2). Within the last decade or so it has also been determined that the bottlenose

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*Reprinted from Science, August 10, 1962, Vol. 137, No. 3528, pages 399-404.

dolphin--and probably the larger-toothed whales as well--navigate in the ocean by emitting trains or series of underwater sonic pulses (3). Dolphins may be able to distinguish one food fish from another by this method (3). Some nocturnal birds (4), and even blinded laboratory rats (5), employ echo ranging to some degree for orientation in space. Thomas C. Poulter of the Stanford Research Institute has recently found that the California sea lion emits trains of echo-ranging signals like those of the bottlenose dolphin (6).

In the light of all this it seems surprising that human beings, with their superior neural and sensory equipment, make so little use of sonic echoes in daily life. In fact, echoes are usually considered to be a hindrance rather than an asset in auditory perception, and when they are noted at all, they are often the cause of special comment. In acoustical engineering great emphasis is placed on designing rooms and wall surfaces which are "anechoic"--that is to say, which reflect few if any echoes. A blind man tapping with a cane--and hence producing a regular sequence of sound pulses--is probably the closest human analogue to the remarkable sonar systems of the porpoise and the bat. With some embarrassment, I quote here a recent statement of my own on this subject (3, p. 48): "the avoidance of objects by the blind appears to be very crude when compared to the precise auditory perception of which bats are capable." The present article gives newly obtained data in partial refutation of this statement. It shows just how accurate the echo ranging of experienced blind people can be.

OBSERVATIONS OF BLIND PEOPLE

Of course the avoidance of obstacles by the blind is by no means a recently observed phenomenon. The "amazing ability" of an unusual blind person to detect objects was described by Diderot in 1779 (7). A number of other outstanding cases have been studied since that time. Current tests of this "obstacle sense" of the blind have demonstrated how much the skill can vary from one person to the next. A few blind people seem to lack it altogether (8). Research has shown, however, that it is not a special endowment and that blindfolded normal (or seeing) subjects can *learn* with practice to detect objects in a manner similar to that of the genuinely blind (9).

The precise mechanism by which this is accomplished when vision is eliminated was not altogether clear prior to the work of Dallenbach and his associates (10). The skin of the face was presumed by some to be particularly sensitive, and it was supposed that the blind detected objects by changes in air currents or in air pressure. Blind observers had reported, in fact, that covering

the face seriously affected their ability to avoid obstacles. The term *facial vision* was applied to this apparent perception through the skin.

Through a systematic study of the matter, however, it was demonstrated that the crucial cues were actually received via the acoustic receptor, and that the subjects were probably responding to echoes. McCarty and Worchel (11) found a blind boy who could avoid obstacles when riding a bicycle. The boy made "clicking" sounds with his mouth while navigating and listened to the echoes of his own noises.

Electronic echo-ranging devices based both upon the reflection of ultrasonic echoes and on the reflection of light beams have been constructed to assist the less-skilled blind in moving about (12). The operator aims the apparatus as he walks, and it sounds a buzzer or otherwise signals when he is close to an obstacle. Such devices have generally not proved popular with the blind probably because (i) the equipment has to be carried and (ii) it has to be overtly manipulated in order to produce satisfactory results.

It is worthy of note that previous studies of the navigational talents of blinded human beings have, for the most part, been qualitative or descriptive in nature. They have been concerned, in other words, with investigating the obstacle sense--with finding out how well blind people could avoid certain barriers or obstructions, and with the mechanism of this avoidance. Since it had been shown (3, 13) that porpoises can distinguish between objects of different size by echo ranging, the question arose as to whether the blind could accomplish the same thing. If the answer was "Yes" would it then be possible to obtain quantitative or numerical measurements of this ability? Could threshold fractions for echo ranging be calculated in the same way that $\Delta I/I$ is computed for visual distance and for size perception? What would the psychophysical function look like? Would Weber's law hold in such a case? Last but not least, do we have here a procedure for comparing quantitatively the sonar of human beings with that of the bat and the porpoise?

Taking off from a group of questions like these, we set up a series of experiments to measure the sensitivity of blind and seeing observers to changes in the distance, size and texture of various stimulus objects. The results have by no means answered all of the questions, but they do seem to offer considerable promise for the application of psychophysical techniques to the sonar system of the blind (14).

SUBJECTS AND GENERAL PROCEDURE

The subjects were four male college students, three of them juniors and the fourth a postgraduate student. Two were completely blind and had been so for 5 and 10 years, respectively. The other two served as normal controls and were blindfolded by means of opaque goggles during all of the tests. Each of the blind individuals was very skillful in navigating and used a collapsible cane only occasionally, or in a noisy environment. Even then it was not used for "tapping" but rather as a protective probe.

The research work was conducted in a sound-insulated experimental chamber approximately 12 by 9 feet in area, with a ceiling height of 11 feet 4 inches. The noise level in the room was down about 10 decibels from that in adjacent rooms. Preliminary tests in research cubicles which were more completely sound-proofed appeared to disturb one of the blinded subjects and to reduce his accuracy. Some degree of extraneous noise was therefore deemed to be better than none at all. This may well mean that blind people, depending as they do so heavily upon hearing, are "lost" and anxious in acoustically pure surroundings which fail to return familiar reverberations.

The echo-ranging targets or stimuli to be observed were flat discs made of quarter-inch plywood and of other materials. They were presented to the subject individually but in rapid succession. Judgments were always made between two successive stimuli of a pair. This permitted the use of the method of constant stimuli (the method of constants), and the method of paired comparisons. All discs were presented on a level with the subject's face when he was seated, and at measured distances from his face.

By a system of small ropes and bicycle wheels (used as pulleys), the distance of a given disc from the observer could be quickly changed. With additional equipment, two separate discs, each differing from the other, could be presented successively. The observer began sending echo-ranging sounds upon a signal from the experimenter. As soon as a judgment had been made, the apparatus was reset, and the subject was told to start on the next target. In making a judgment, the subject simply stated: (i) whether a single disc was nearer or farther away than it had been during the previous presentation, a moment before; (ii) whether one of two successively presented discs was larger or smaller than the other member of the pair; and (iii) whether or not a disc was of the same material as the disc with which it was compared.

AUDITORY SCANNING

The subjects were not restricted in any way with respect to the

noises they made. They were told to make "any sounds they wanted." The object was not to study the effectiveness of different sorts of acoustic signals but rather to find out what blind people could do by using any or all signals at their command. Both of the blind subjects in these experiments employed tongue-clicking to some extent--a sound reminiscent of the sonar "pings" of the porpoise. Sometimes they snapped their fingers a few times. They also resorted to hissing and, on rare occasions, to whistling.

By far the preferred source of auditory signals, however, was the human voice, which was used in a repetitive and sometimes in a sing-song fashion. One of the subjects actually sang the diatonic scale, or part of the scale. He would also repeat the word *now* by saying, "Now, now, now, now, now ..." varying the pitch of his voice as he did so. The other subject fell into a speech pattern somewhat like the following:

"Now, this is the . . . this is the . . . uh . . . let me see . . . now, this, I think, is the smaller (or larger) disc."

The blindfolded normal subjects also used vocal signals, for the most part. One of them, who was studying Russian, chose continuously to repeat the Russian word *"dva."*

While the sounds were being emitted and the judgment was being formulated, each of the blind observers oscillated his head from side to side at angles varying from 5 to as much as 45 degrees on either side of the median plane. This behavior is particularly significant, we think, since it is precisely the method used by the bottlenose porpoise in locating a target in turbid water. Head oscillations in the porpoise have been noted by Schevill and Lawrence (15), by myself (13), and by Norris *et al.* (16). I have described the phenomenon in detail (3, 17) and have given it the name of "auditory scanning." Auditory scanning is a combination of echo ranging and binaural localization. The lateral oscillations of the head continuously modulate the intensity and phase differences of the echoing sound waves reaching each of the ears. By accentuating the difference in the echoes received by the two ears, the oscillations enhance the accuracy of perceiving the target.

On some occasions, surprisingly enough, one of the blind subjects moved his head up and down as he was making the sounds. In spite of the generally vague or poor directionality of the human voice, it appeared as if he were trying to "aim" the sound at the circumference of the disc in order to pinpoint the location of its edge. With vertical oscillations of this sort, the differential binaural effect produced by the echo would of course be low. The normal control subjects did not use any form of oscillation very much, although they tried on occasion to imitate the blind in this respect.

For this experiment a single disc 1 foot in diameter was used. It was made of 1/4-inch fir plywood and was painted with a sand-texture paint to give a hard, diffuse reflecting surface. The disc was moved silently by the experimenter to one of seven fixed positions at distances from the face of the observer which varied from 1 foot to 3.97 feet. Each position therefore constituted a separate "stimulus" to be judged. The standard position (St) was at 2 feet. Three of the comparison stimuli (L3, L2, and L1) were closer to the observer and consequently appeared larger than the standard. The remaining three (S1, S2, and S3) were farther from the observer and appeared smaller than the standard. A given comparison stimulus was always compared with standard stimulus and never with another comparison stimulus or with itself; nor was the subject required to compare standard with standard. The subject compared L3, L2, L1, S1, S2 and S3 respectively, with the standard, making 100 judgments in each case. The arrangement for moving the stimuli is shown in Figure 1.

Figure 1. The arrangement for presenting the stimuli in the distance-discrimination or depth-perception experiment. The disc used as a target is silently moved to one of seven fixed positions.

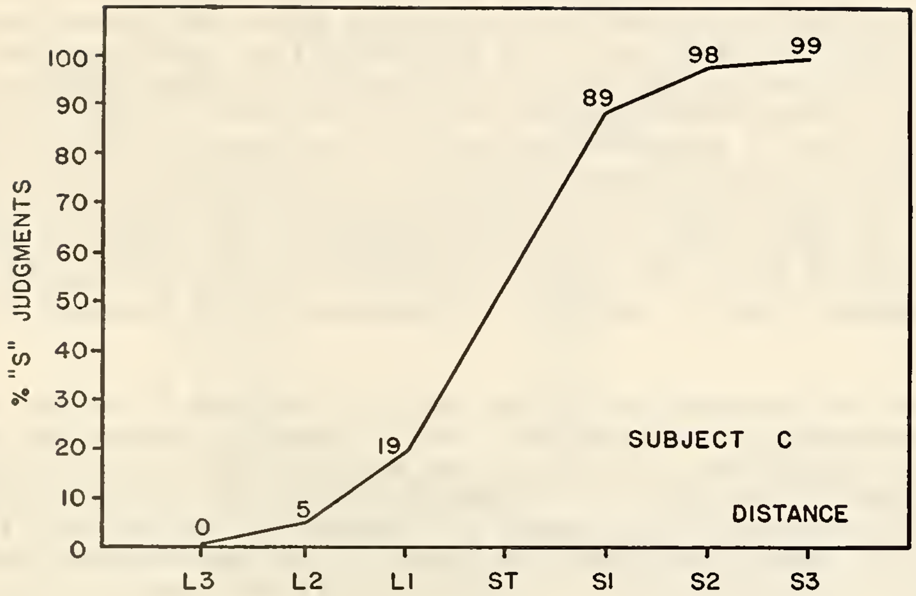

Figure 2. Psychophysical curve for one of the blind observers in the distance-discrimination experiment. The stimuli are given on the abscissa. The numbers above each point on the curve represent the percentage of "smaller" judgments for that point. This graph is similar to those obtained in measuring sensitivity in vision and in other sense modalities.

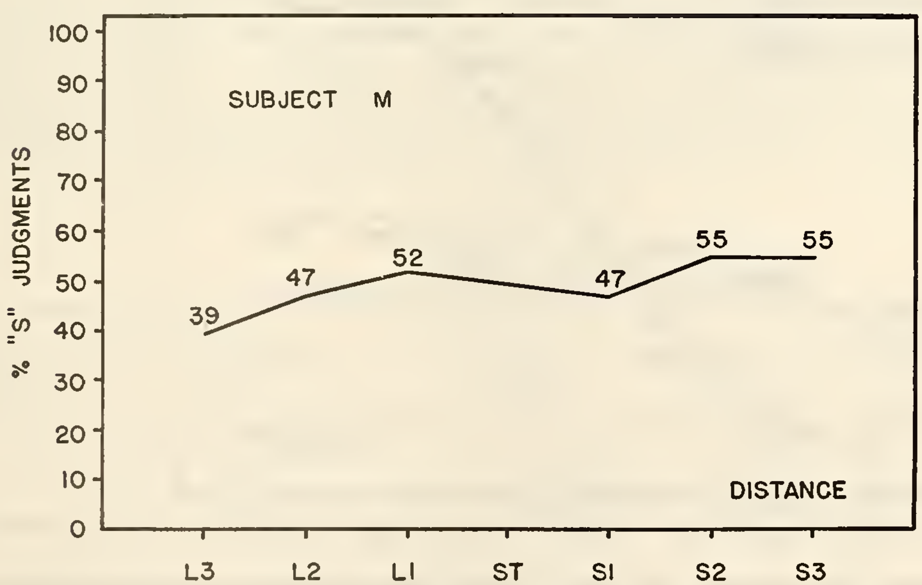

Figure 3. Graph of "smaller" judgments for one of the seeing subjects in the discrimination of distance. Compare this with Figure 2.

The observer in the experiment always knew that one of the stimuli of any given pair was closer to him than the other member of that same pair, but the order of presentation (for example, presentation of L3 before St, or of St before L3) was randomized. A person totally unable to perceive any difference in the distance of the two would get a score of 50 percent (chance accuracy). Any percentage greater than 50 would indicate some degree of perceptibility, provided there was no constant error. The characteristics of the stimuli at the seven stimulus positions are shown in Table I. It may be noted that the angle subtended at the different positions extended from 14 degrees 22 minutes to 53 degrees 08 minutes.

A standard psychophysical curve may be plotted from the data by using the percentage of "smaller" (or "larger") judgments made at each stimulus position. Such a plot for one of the blinded subjects is given in Figure 2. A comparable graph for one of the normal or seeing observers is shown in Figure 3. In Figure 4 there is a single combined psychophysical function for the two blind subjects, together with a similar combined curve for the normal blind-folded subjects.

The psychophysical curves for the blinded observers, it is clear, follow the typical pattern of psychophysical graphs obtained in measuring sensitivity in the visual, auditory, kinesthetic, and other sense modalities. By contrast, the graphs for

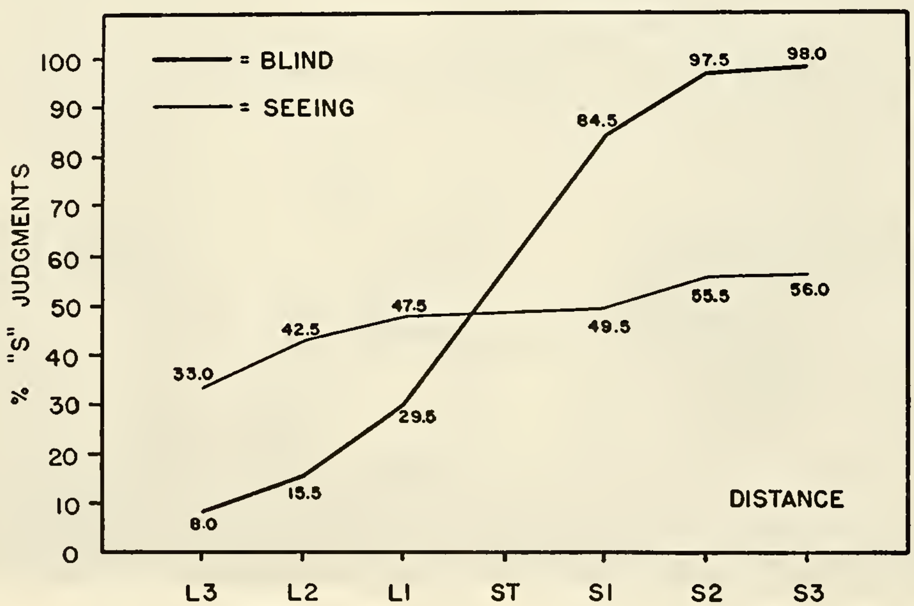

Figure 4. The performance of the blind versus the seeing subjects on judging distance. All points on the "seeing" curve, except that at the extreme left, are within the limits of chance expectancy.

TABLE I

CHARACTERISTICS OF TARGET STIMULI
(the same 1-foot disc was used at different distances)

Position	Distance from 0 (ft)*	Approximate projected or perceptual area (sq ft)**	Angle subtended (deg	min)
L3	1.00	0.785	53	08
L2	1.26	.489	43	12
L1	1.59	.310	34	52
St	2.00	.196	28	04
S1	2.55	.124	22	10
S2	3.19	.078	17	50
S3	3.97	.049	14	22

*Each distance is about 126 percent of the next smaller distance; therefore, the differences are relative.
**Each projected area is about 158 percent of the next smaller area; therefore the differences are relative.

the seeing observers show a sensitivity which at most points is so poor that it is not significantly greater than chance performance (18).

The threshold values, computed from z-scores, for the two blinded individuals, are given in Table II. A single example of the significance of these figures may be seen in the distance threshold for subject C--the better of the two blind people at auditory scanning. It appears that this observer could detect, by echoes, a change in the position of a 1-foot disc placed 2 feet away from him when that disc was moved nearer or farther away by a little more than 4 inches. The other blind observer was not so accurate.

TABLE II

THRESHOLDS FOR DEPTH PERCEPTION

Subject	Distance (in.)	Area (ft^2)	Area ($in.^2$)	Auditory angle (deg	min)
C	4.3	0.076	11.0	4	42
W	7.2	.128	18.4	7	56

The threshold fractions for the blind in terms of distance, projected area, and auditory angle are given in Table III. They range, it may be seen, from about 1/1.5 to about 1/7, with an average of about 1/4. It is worthy of note that the visual

threshold for depth perception, as measured by Howard (19), is on the average about 1/2 for monocular vision and about 1/40 for binocular vision.

TABLE III

△ I/I FOR DEPTH PERCEPTION

Subject	Distance	Perceptual area	Auditory angle
C	1/5.6	1/2.6	1/6.7
W	1/3.3	1/1.5	1/3.6

The average fraction for monocular depth perception, according to these figures, is larger than the average obtained from echo ranging. If direct comparisons are made (their value is somewhat questionable), this means that an experienced blind person can perceive differences in distance better than a person using only one eye. Visual thresholds of this sort are, however, obtained without head movement, and oscillations of the head were extensively used by the subjects of this research.

In the experiment just described we held size constant and placed a single disc at varying distances from the subject. To test for size discrimination, these conditions are reversed. In this case we must hold distance constant and very the absolute size of the targets used as stimuli. This was accomplished by using seven painted wooden discs, like the disc employed for distance perception. The standard stimulus was 9.4 inches in diameter, and the comparison stimuli ranged from 5.8 to 12.0 inches. The entire experiment was performed three separate times for each individual at distances of 12, 18, and 24 inches. The auditory angles subtended by the discs at a distance of 24 inches, for example, ranged from 13 degrees 48 minutes to 28 degrees 04 minutes, with the standard subtending an angle of 22 degrees 10 minutes.

In any given series of 100 judgments, the standard and one of the comparison stimuli were fastened to the circumference of a 28-inch bicycle wheel, which was mounted horizontally on a level with the observer's face. The two discs were placed 90 degrees apart on the circumference of the wheel, and perpendicular to it. By rotating the wheel, the experimenter could move either disc so as to bring it directly facing the observer. The disc which was not facing the observer was then edgewise with respect to him. As a result, it offered little or no reflecting surface. Either disc could in this way be moved into position as a target at the same time that the other disc of the pair was moved out of position. Figure 5 is a posed picture, taken outside the sound-insulated room, which illustrates this arrangement

for presenting the stimuli in the test for size discrimination.

Figure 5. The arrangement for presenting the stimuli in the size-discrimination experiment.

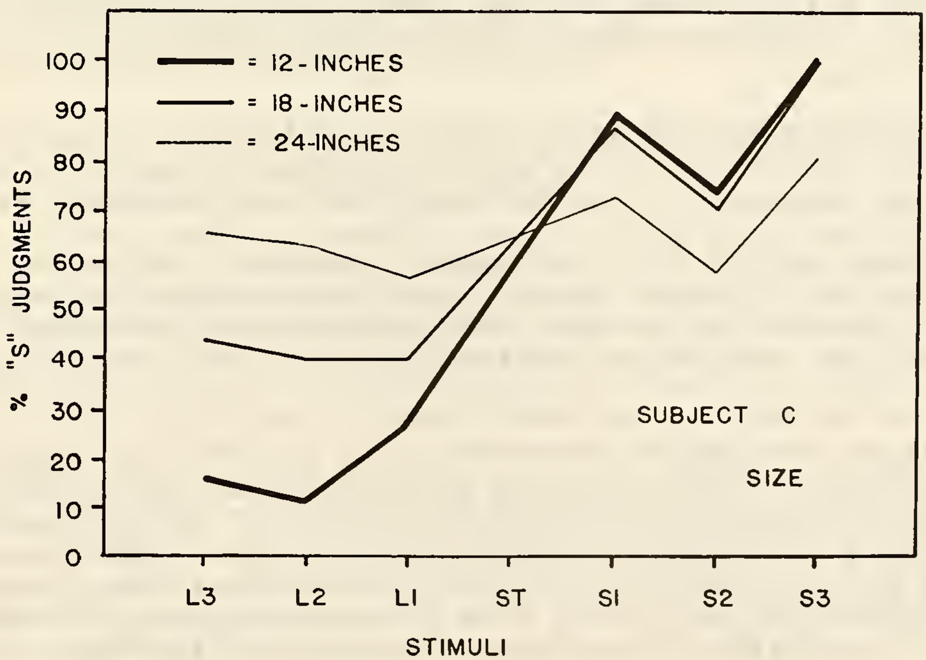

Figure 6. Size perception for one blind observer at three different distances. The sensitivity seems to break down for this individual as distance is increased (particularly in the case of the larger stimuli) but this rule did apply for the other blind subject.

The general results, while not so striking as those for distance perception, are nevertheless remarkable. As an example, we present in Figure 6 the data for one of the blind individuals (subject C). The psychophysical function is fairly good at a distance of 12 inches but becomes progressively poorer, particularly with the "L" (the larger) discs, as the distance is increased. The judgments of subject W, on the other hand, did not show this peculiar effect, and his graphs (not shown here) for all three distances were more alike, although not as good as those for subject C at 12 inches (20). We consider these abberations to have been partly due to the apparatus and believe that with better instrumentation they would be less likely to occur.

PERCEPTION OF TEXTURE AND DENSITY

Sonar operators at sea have not infrequently mistaken the echoes returning from a submerged whale for those of a submarine, and Navy lore contains numerous tales of harmless cetaceans which have been depth-charged because of this mistake. Since different materials have different absorption characteristics, for sonic vibrations as well as for light waves, one wonders why the echoes returning from whale blubber should not be easily distinguished from those returning from the steel hull of a ship. The bottlenose dolphin, moreover, seems to have no difficulty in detecting the difference between a water-filled plastic bag and a food fish (15), and between the human hand and a food fish of the same size (3). Can blinded human beings similarly differentiate between targets of different materials merely by listening to the echoes they reflect?

To investigate this matter, six 1-foot discs, all with different surface characteristics, were presented in pairs to the subjects. The distance of presentation was held constant at 12 inches. The discs were made of the following materials: 16 gauge galvanized sheet metal; 1/8-inch glass, mounted on 1/4-inch plywood; 1/4-inch fir plywood, painted with sand-texture paint; 1/4-inch fir plywood, unpainted; denim cloth stretched over a hoop (no backing); and velvet cloth stretched over a hoop (no backing).

Each disc was paired with every other disc by the method of paired comparisons. Each disc was also compared with nothing--that is to say, with no disc at all--to find out if its mere presence or absence was easy or difficult to detect. The discs were presented as in the size discrimination experiment (see Figure 5), and 100 judgments per pair were made by each subject. The results for the two blind individuals are combined in Table IV.

Table IV gives the percentages of trials in which the two subjects were correct in their judgments; a score of 50 percent indicates pure guessing or no ability to distinguish. All percentages of 59 or more in this table differ significantly from

TABLE IV

ACCURACY (PERCENT) WITH WHICH DIFFERENT MATERIALS WERE DISCRIMINATED BY SUBJECTS C AND W

	Velvet	Denim	Plain Wood	Painted Wood	Glass	Metal	Nothing
Velvet							
Denim	86.5						
Plain wood	99.5	94.5					
Painted wood	99.5	96.5	47				
Glass	99	86.5	52	54			
Metal	99.5	90.5	69	58.5	47		
Nothing	94.5	97.5	100	100	100	100	

chance at the 1-percent level of confidence. In a general way, the results point to a distinction between "hard" or good reflecting surfaces and "soft" or poor reflecting surfaces. Thus it may be seen that the echoes from painted wood and glass cannot be separated. Painted wood is also indistinguishable from metal. All of the discs were easy to tell from no disc at all, although the scores are slightly lower for the softer discs than for the harder ones. Surprisingly, denim cloth and velvet can be differentiated 86.5 percent of the time.

We have here clear evidence that the echoes returned from many of these substances are sufficiently distinctive for skilled observers to identify them.

It was not at first recognized that skillful blind people who detected obstacles without a cane or other special aid were actually using the method of echo ranging or sonar, like the porpoise and the bat. For the most part, research on this matter has been qualitative or descriptive in that it sought to discover how well the blind could avoid barriers or obstacles. In the experiments described we have attempted to measure by psychophysical methods the ability of the totally blind to differentiate between stimulus targets which varied from one another in size, in distance from the observer, and in texture or absorption characteristics. The judgments of the subjects were made entirely by listening to echoes which were reflected back from the separate targets. Blindfolded subjects with normal vision acted as experimental controls.

Each observer made his own noises and used whatever natural sounds he considered best. These included talking, singing, whistling, hissing, snapping the fingers, and tongue-clicking.

The method of constant stimuli (the method of constants) and the method of paired comparisons were employed to determine sensitivity. Psychophysical curves and threshold values were computed.

The distance of depth perception of one of the blinded individuals was such that he could perceive a movement of 4.3 inches of a 1-foot disc placed 2 feet in front of him. Threshold fractions for this ability averaged about 1/4 and compared favorably with those for monocular depth perception. The discrimination between objects of different sizes, with distance constant, was not so accurate but was nevertheless remarkable. The blinded subjects could also distinguish between targets of the same size which were made of metal, wood, denim cloth, and velvet. Each of these objects simply "sounded different" from the others. Objects of similar density, on the other hand - for example, painted and unpainted wood, or metal and glass - were indistinguishable. The judgments of the normal control subjects were almost never above the level of pure chance.

These unusual performances show that some blind people can observe amazingly well by means of human sonar. Future research on this question may bring to light achievements that compare favorably with those of the porpoise and the bat.

REFERENCES AND NOTES

1. D. R. Griffin, Listening in the Dark (Yale Univ. Press, New Haven, 1958).

2. S. Dijkgraaf, Isis 51, 9 (1960).

3. W. N. Kellogg, Porpoises and Sonar (Univ. of Chicago Press, Chicago, 1961).

4. D. R. Griffin, Proc. Natl. Acad. Sci. U.S. 39, 884 (1953).

5. J. W. Anderson, Science, 119, 808 (1954); J. F. Dashiell, J. Comp. and Physiol. Psychol. 52, 522 (1959); D. A. Riley and M. R. Rosenzweig, ibid., 50, 323 (1957).

6. Letters and personal discussion.

7. D. Diderot, Early Philosophical Works (Open Court Publishing Co., Chicago, 1916).

8. P. Worchel, J. Mauney, J. G. Andrew, J. Exptl. Psychol. 40, 746 (1951).

9. C. H. Ammons, P. Worchel, K. M. Dallenbach, Am. J. Psychol. 66, 519 (1954).

10. M. Supa, M. Cotzin, K. M. Dallenbach, *ibid.* 57, 133 (1944); P. Worchel and K. M. Dallenbach, *ibid.* 60, 502 (1947); M. Cotzin and K. M. Dallenbach, *ibid.* 63, 485 (1950).

11. B. McCarty and P. Worchel, *New Outlook for the Blind* 48, 316 (1954).

12. P. A. Zahl, Ed., *Blindness: Modern Approaches to the Unseen Environment* (Princeton Univ. Press, Princeton, N. J., 1950).

13. W. N. Kellogg, *Science* 128, 982 (1958); *J. Comp. and Physiol. Psychol.* 52, 509 (1959).

14. These investigations were supported by a grant from the Research Council of Florida State University and by aid from the psychology department. We are greatly indebted to Mr. Stephen Feinstein and Miss Joan Helmrich for assistance in obtaining and working up the data.

15. W. E. Schevill and B. Lawrence, *Brev. Museum Comp. Zool.* Harvard 53, 1 (1956).

16. K. S. Norris, J. H. Prescott, P. V. Asa-dorian, P. Perkins, *Biol. Bull.* 120, 163 (1961).

17. W. N. Kellogg, *Psychol. Record.* 10, 25 (1960).

18. Percentages of 59 or greater and of 41 or less are significant at the 1 percent level of confidence.

19. H. J. Howard, *Am. J. Ophthalmol.* 2, 656 (1919).

20. The normal controls had no more success in this experiment than in the previous one.

TRIAL OF AN ACOUSTIC BLIND AID*

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INTRODUCTION

This report deals with the evaluation of an acoustic blind aid developed by Dr. Leslie Kay (2) of the Department of Electrical Engineering, Birmingham. The principle of the aid is that a narrow cone of space is explored by a hand-held "torch"; any object within this cone produces a signal in a miniature headphone, whose frequency is determined by the distance of the obstacle, and whose loudness depends primarily on the nature and orientation of the reflecting surface. We had to decide whether blind people found this device helpful in practice.

It should be noted that this trial was regarded as one phase of a wider program in the development of electronic guidance aids, and the results are considered in this light in the Final Discussion. Although we had available for evaluation only one particular type of aid it was felt that sufficient information regarding the principle of a frequency modulated echolocating device could be obtained.

The trial was in two parts: at Worcester College for the Blind (WCB) and at St. Dunstan's establishment at Ovingdean. The two parts are described separately, and some general comments made at the end.

THE WORCESTER EXPERIMENT

In almost every respect we expected Worcester College for the Blind to provide the most favorable conditions for the aid. The schoolboy subjects were at the most adaptable age, and as the College is the only residential grammar school for blind boys in the country, the boys are highly selected for general ability.

Our trial made considerable demands upon headmaster, staff, and boys and we are very grateful for their unfailing cooperation. We estimate that the boys who used an aid gave up some 14 hours, and the control boys 8 hours; most of this was taken from school time. This may account for some of the enthusiasm they showed,

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but with the older boys, with examinations in mind, this factor probably worked the other way.

In retrospect, our tests of the performance of the aided boys now appear less adequate than they might have been. However we all started this work with no previous experience of the blind, and the available literature gave us no help in understanding what the blind could do with no artificial help. In fact it was not until after several weeks of increasing acquaintance with the daily life of the boys that we realized how important was this question which we should have asked at the beginning, namely, to what extent can the kind of performance claimed for the aid be achieved by unaided blind people?

One good example of this was that in teaching the use of the aid, we were delighted to find how well aided boys could "follow my leader," one of us moving quietly, quickly, and irregularly about a lawn, and the boys following at a distance of ten feet or so without fault. It was then rather unnerving to find that the boys could do just the same thing with no aid at all, and that in fact this was one of the games instituted by the physical education master. A contrasting example proved to be the difficulty all the boys had in identifying and passing through a narrow gap between bulky obstacles. This proved very difficult for unaided boys, and those with the aid took a correspondingly long time to learn how to do it.

Our problem, as we expressed it at the start, was to find out whether the aid would improve the boys' ability to move about independently, either in terms of an objectively measurable change such as speed, or a partially subjective assessment such as a count of obstacles avoided, or in terms of an improvement in confidence or a lessening of strain. There were two ways in which we could arrange an experiment to show this; either we could compare each boy's performance with and without the aid, or we could train one group of boys in the use of the aid and another without, and compare the two groups with each other.

The second alternative was chosen as more suitable for two reasons. First, it was likely that there would be interaction between using an aid and moving about unaided. Either one may help the other, or by learning to rely upon the aid the boys may come to neglect their natural cues to orientation when unaided. Second, we wanted to find out whether we could improve the mobility of unaided controls by encouragement, practice, or suitable training, and to compare the effort put into this with that required by the aided group.

In short, we had to ensure that whatever benefit resulted from using the aid was not an experimental artifact, but at the same time we wished to give the experimental boys all the advice,

encouragement, and training which we could devise in making the best use of the aid.

It may be noted in passing that we were only able to compare performance with the aid with the same performance with no aid. We were in no position to compare the acoustic aid with other aids such as the cane or the dog.

Testing Methods

Ideally we would have set up a standard task such as an obstacle course and measured the boys' performance of the same task at various stages. In practice it was necessary to work out the best arrangement of test as we went along. We soon discovered that some types of obstacle appeared to favor one group and others the other group, yet neither might be typical of the hazards met in everyday life. We therefore varied our test course each time, searching for a sensitive and realistic measure. A number of obstacles were used in each of the last three tests, the differences being in their separation and the means of marking the route from one to the next. Although the courses were changed from one test occasion to the next, yet on each occasion the experimental and control groups had the same course so that valid and controlled comparison remained possible.

This changing of our test course was naturally more extensive in the earlier stages, after the pretest and the first post test. At this time also, after the first post test, we changed our policy more drastically and devoted more time to deliberate training of the experimental group. For these reasons we now regard this earlier part of the experiment as preparatory and most of the results which will be presented refer to the later tests, all of which were obstacle courses set up on the College athletics ground. Apart from the controlled observations, we also took account of observation of the boys in ordinary circumstances, and of their opinions.

Subjects in the Worcester Experiment

The boys in the school are all "educationally blind" - a term which covers quite a wide range of disability and includes many with sufficient vision to enable obstacles to be avoided. There were 21 boys who were either totally blind or who were described as having perception of light only, and who had been at the school for at least two years. Their ages ranged from 12 to 19; two of the boys were blinded at the ages of 13 and 15 years, and all the remainder had been blind from birth or infancy. Audiograms were taken of all the boys and none found to be appreciably below normal in hearing.

We asked all the masters who knew the boys and could do so,

to give each boy a rating on a five-point scale with respect to confidence, mobility, and general ability. On the basis of these ratings, together with age, onset and degree of blindness and hearing, pairs of boys were selected, matched as accurately as possible. The eight best matched pairs formed the experimental and control groups; from each pair the choice of which boy entered the experimental and which the control group was random. The remaining two pairs and one odd boy were retained as reserves and treated as members of the control group.

From seeing the activity and mobility of the boys within the school and the grounds it is difficult to believe that they are blind. The exuberance and mischief of boys is quite as marked in them as in the sighted. Few of the younger boys would venture into the city of Worcester by themselves, but some of the older ones did so. There is a tendency to go about in small groups, a partially sighted boy leading the blind.

The cane we found to be used hardly at all by these boys, although its use was not actively discouraged. We had the impression that there was a bias against its use since it identifies the boys as blind and thus distinguishes them from other boys. We also gathered that at medical examinations the boys are prone to try and claim more vision than they actually possess. Thus we have two clear instances of a tendency in this blind population to minimize their distinction from their sighted fellows. It is worth noting in contrast that among the older people at Ovingdean there appeared to be a bias in the opposite direction.

The boys reflected the cooperative spirit of their headmaster, and both control and experimental groups appeared to remain well motivated throughout the experiment. Although we never gave any results, either numerical or verbal, which would enable the two groups to compete with each other, the motivation appeared rather to result from the challenge which our obstacle courses offered to each boy individually. Similarly they all appreciated the chance to go into the crowded city, and such street drill as we could give them was well accepted. In spite of the tendency mentioned in the previous paragraph there was little evidence that boys of the experimental group had any misgivings about making themselves obvious by carrying a strange instrument.

In instructing these boys, most of whom had been blind from birth, we had verbal difficulty for quite some time, resulting from their nonvisual conceptualization of the world. The boys used visual language, but probably as a convention. We tended to make unthinking use of visual description, which was apparently accepted by the boys, but was followed by evidence of misunderstanding. For example it proved very difficult to describe the

diverse forms of shop fronts as they were approached. This difficulty was not found at Ovingdean with any of the older subjects, all of whom had been sighted at least until early manhood.

The Tasks Used at Worcester

Master's Ratings

The masters at WCB were asked to rate each of the 21 boys with respect to inherent ability, attainment (a boy's showing in the master's own subject), ability to orientate, confidence, and enterprise. The ratings were from A through E and C was to be regarded as "average for a boy of that age at the College."

Baseline Tests

We hoped to obtain some objective measures of how good the boys were with regard to mobility and orientation. We were not able to discover any standardized tests for this and for all we know such tests do not exist. Our attention was drawn to a monograph by Worchel and we adapted one of the tests suggested by him, the right-angled triangle test (5).

a) Moving along the corridors from the workshop to the gym; the score taken was time to complete. Owing to a misunderstanding the course was made to include a diagonal crossing of the gym.

b) Circling the main building from the back door of the gym in a clockwise direction, a distance of some 360 yards. The score being again the time taken to complete the circuit.

c) Right-angled triangle test: each boy was taken along the two sides of a right isosceles triangle with a 14-foot hypotenuse. The first time around the experimenter led the boy back to the starting place. On the three following trials the experimenter left the boy to make the final turn and attempt to walk back along the hypotenuse to the starting place. The score was the distance between stopping and starting place (5).

Pretest

In order to see how good the boys were at dealing with obstacles prior to any of our training we placed various obstacles along part of the circuit used for (b) above. The score was time taken and a combined detection/negotiation score.

Post Tests

These were intended to measure the progress of the boys in the two groups. For a discussion of the difficulties encountered see Appendix A.

The first post test was carried out over the same course as the pretest, merely rearranging the obstacles.

The second post test and the two others were carried out on the College's athletic grounds. For the first course the obstacles were arranged in a closely packed semicircle. One of the aims was to see whether such a course, in which movement between obstacles would account for very little of the time taken, would provide a more sensitive measure than the first post test (Figure 1).

The third post test was a most elaborate affair with obstacles well spread out and much of the space between obstacles taken up by some hundred yards of beech fencing. On this occasion one obstacle (the Thick Forest, see Figure 4) had to be negotiated in the presence of noise switched on by the experimenters. This whole course was traversed twice by the boys: once with instructions to go slowly and carefully, and once with the instructions to get from start to finish as quickly as possible without actually inflicting any damage on themselves (Figure 2).

The fourth post test was the longest in extent and incorporated all the obstacles which we had come to regard as useful. The connection between obstacles was by guide-ropes (Figure 3).

"Psychophysical Test"

A simple task was designed to see whether the boys with the aid could judge distance when the echo was produced by reflection from different kinds of material. The situation and results are described below.

Boys' Rating

After completing the fourth post test each boy who had been trained with an aid was asked how highly he would rate the aid in comparison with the Perkins brailler (or best brailler they know of) having a rating of 10, indifferent at 5, and useless as 0.

Street Circuit

There was a form of street test circuit used by us on the last two days of the actual experiment: the boys were taken down The Shambles, up St. Swithin's Passage, and back along High Street. The final part of the course, some 50 yards, was filmed from a first-floor window in a house opposite.

Training Tasks

Apart from the various scored tests listed above we set up a number of training tasks for both groups of boys.

Figure 1. Part of the obstacle course used for the second through fourth post tests.

Figure 2. Another view of the course. Boys always entered from the left.

Figure 3. An experimenter acts as a pedestrian to be avoided in a narrow alley.

Figure 4. A boy going through Thick Forest in the presence of noise. The noise is produced by the "rattle" seen in the center of the photograph.

For the Boys Trained with Aids

Introductory Training: of distance and surface judgment (L.K.)

Holding on to Hand: of blindfolded experimenter (L.K.) while he walked along a moderately familiar part of outside path at WCB guiding himself by means of aid. This was a first attempt at showing the boys the kind of scanning movements required as well as the necessary inferences to be made about the echoes (3).

Obstacle Location Course: Set up in Orchard by L.K. - 5/11/62.

Individual Obstacle Detection Course: Set up on playground by L.K. - 5/15/62 (Figure 5).

A Distant Object Training Course: Set up on rough ground by the Malvern lawn at WCB. This course consisted of a number of posts strung out along a line of irregular shape, each post about ten feet from the next. There were some double posts set up in the form of gates, and towards the end of the course some small trees were near enough to be confused with the posts. These obstacles were small enough, and placed at sufficient distance, for the boys not to be able to pick them up except by means of the aid. We hoped that this arrangement would encourage the various types of scanning movements thought necessary for full use of the aid. The boys were not merely asked to find and avoid successive posts or gates but also to circle them. A shortened version of this course, with successive posts braille numbered was left in position for a number of days.

Town Courses: These varied in complexity depending on our intention. We started with a treelined promenade by the river, with no vehicular traffic and very few pedestrians; made use of two circuits in the center of the city where the boys encountered almost everything they were ever likely to encounter by way of stationary and mobile obstacles as well as traffic noise; and picked one built-up "island" surrounded by fairly constant heavy traffic to practice the avoiding of oncoming pedestrians.

For the Boys Trained without Aids

Obstacle Detection Course: This was set up on the boys' playground at the suggestion of Mr. Jones (an extremely mobile, blind gentleman), and consisted of a number of obstacles arranged in an inner rectangle (see Figure 6). The boys' task was to walk between the obstacles and the fence and lift their hands whenever they thought they could detect an obstacle. They did this once assisted by Mr. Jones and three times by themselves, watched by the experimenter.

Obstacle Negotiation Course: For this we took three of the

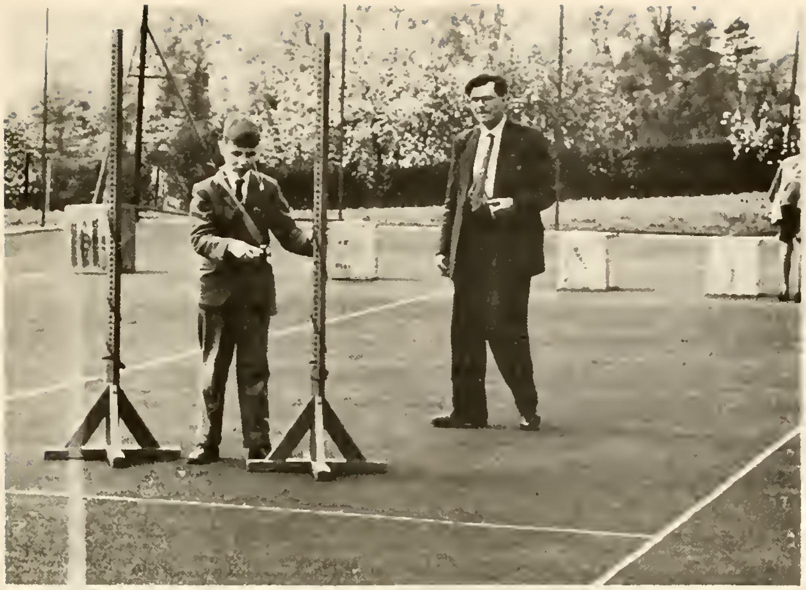


Figure 5. A part of Dr. Kay's training course.

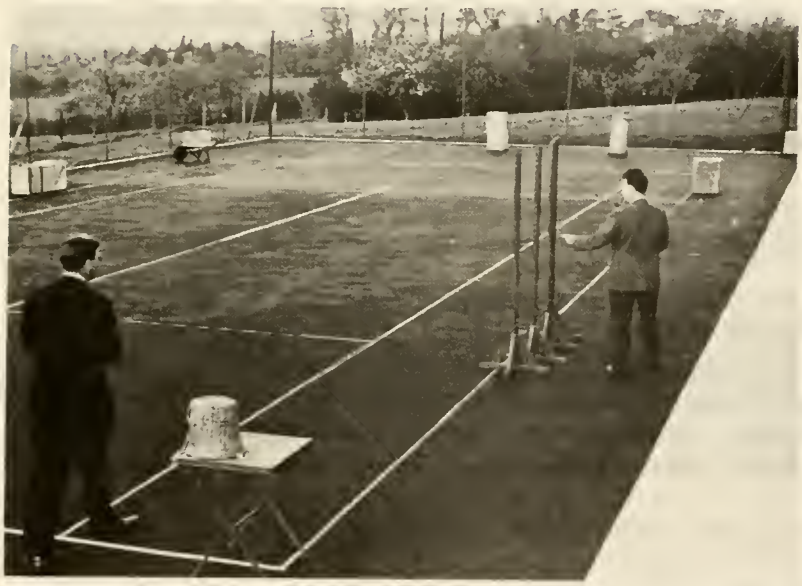


Figure 6. Mr. Jones' training course.

obstacles used in the first two obstacle courses and tried to train the boys in appreciating them.

Training on Distance Judgments: Here we tried to find out how well the boys could judge their distance from an object once

they had detected it. They were instructed to approach a tree or the wall of the house until they were within one, two, or three arms' lengths away from it. This was one of the tasks the boys were encouraged to carry out while the experimenters were not with them.

Town Courses: By and large these were the same as those described under Town Courses above. With these boys, however, we were able to concentrate more on a basic form of street-drill; e.g., making the distinction between street and house sides of the pavement and avoiding oncoming pedestrians by stepping to the house side rather than risk stepping off the curb.

Instructions Given to Subjects

General

We had to combine two aims in the work at Worcester: On the one hand we wanted the boys to behave as naturally as possible, and on the other hand we assumed that increased awareness of their environment would be of help to them. Our instructions to both groups therefore incorporated these two aims at all times. With the aided boys we tried to encourage them to think of the cues coming from the aid as additional to any other cues and to learn to combine the new cues with the old ones. For example, towards the end of street training we asked the boys to try to keep their general direction and distance from the shop fronts by normally available cues, and to use the aid primarily to ensure that the forward path was clear.

Obstacle Courses

During tests the boys were encouraged to use their hands and feet to explore obstacles as much as they needed in order to negotiate them. For the last three post tests there was a form of instruction on how to negotiate obstacles, namely: "... try and get around the obstacle; if that is not possible, try to get over or under; and if that is not possible, step onto the obstacle."

Use of the Aid

The tasks used are described above and for the most part the instructions followed the task requirements. The main difficulties arose over explaining the peculiarities of the aid in a manner which the boys could not only understand but could make use of. As we had anticipated one of these difficulties was in getting across the concept of scanning and in keeping the boys at it. To some extent this difficulty was met once we told the boys to think of the beam emitted by the torch as an extension of their hands which allowed them to "feel" for objects several arms' lengths away; that, for instance, while the movement of the searching hand

would be arrested when it encountered an object, the auditory signal would change under like circumstance.

Results of the Worcester Experiment

The numerical results are gathered together in Table I. The boys are listed in the two groups, and those in one list are paired with boys of the corresponding letter in the other list.

Masters' Rating

The figures listed are the sum of six masters' ratings. The ratings in ability, orientation, and confidence were checked statistically and it was found that the masters were highly consistent with each other in their ratings.

Baseline Tests

Of the three tests the only one which it is useful to record was that in which we timed each boy in walking around the College buildings. This circuit, most of which was familiar to the boys, was rather less than a quarter of a mile in perimeter. The boys' mean time of 5 minutes 29 seconds is an indication of their abilities. The shortest time was 3 minutes 55 seconds, representing the creditable speed of 3.1 miles per hour; the longest was 9 minutes 25 seconds. Of the test in which we timed the boys moving within the corridors of the College suffice it to say that although this course included steps going up and down the experimenter had a hard time keeping up with the sprinting boys.

These figures refer to the whole group of 21 boys. All other results quoted refer to the two matched groups of eight boys each.

The Pretest and First Post Test

In these two tests different experimenters scored different boys for negotiation of obstacles, and these counts are therefore not comparable. In this respect the two tests merely gave us the experience upon which to base the later tests.

The times obtained, in minutes and seconds, are as follows

		Median	Range
Pretest	Aided Group	3:59	3:09 to 6:56
	Control	4:45	3:37 to 6:05
Post test	Aided Group	5:47	3:59 to 15:15
	Control	4:24	3:35 to 5:37

These two tests were very comparable in difficulty, and the control group were very slightly faster on the post than on the pretest. The aided group in contrast were slowed by a factor or almost 1.5.

TABLE I

NUMERICAL RESULTS OF THE WORCESTER EXPERIMENT

Aided Group	Age	Onset of Blindness	Nature of Blindness	Degree of Sight
A	19	Infancy	Detached retina sympath.	Nil
B	19	15 years	chemical explosion	Nil
C	17	3 years	Glioma	Nil
D	15	Birth	Buphthalmos	Nil
E	14	Birth	Buphthalmos	P. L.
F	13	Birth	Foetal Iritis Congential	P. L.
G	13	Birth	Retrolental Fibroplasia	Nil
H	12	Birth	Retrolental Fibroplasia	P. L.
Unaided Group				
a	18	2 years	Glioma	Nil
b	18	13 years	Optic Atrophy T.B. Meningitis	Nil
c	17	3 years	Glioma	Nil
d	14	14 months	Glioma	Nil
e	13	Birth	Retrolental Fibroplasis	P. L.
f	12	Birth	Retrolental Fibroplasia	P. L.
g	13	Birth	Retrolental Fibroplasia Glioma?	Nil
h	14	Birth	Retrolental Fibroplasia	P. L.

TABLE I

(Continued)

	Masters Ratings*				Baseline Tests					Pretest	
	1	2	3	4	Triangle ft	Triangle ins	Outside mins	Outside secs	Inside secs	mins	secs
A	7	7	10	11	9	6	4	45	38	3	30
B	17	18	19	17	7	11	7	12	49	5	37
C	22	21	18	20	12	2	4	35	56	3	35
D	16	16	18	18	6	8	4	50	39	3	9
E	15	13	14	12	6	6	4	0	55	3	40
F	17	16	19	19	17	0	6	35	51	4	17
G	21	20	18	21	20	4	9	25	37	6	56
H	17	18	17	16	7	11	6	50	53	5	25
a	13	15	15	14	17	11	4	05	47	3	37
b	13	16	13	12	8	6	5	30	56	5	28
c	12	13	19	17	10	6	5	50	44	6	05
d	15	16	14	13	14	1	3	55	39	4	06
e	14	16	15	15	18	1	8	08	57	4	37
f	18	19	19	18	37	8	5	30	67	4	07
g	17	19	19	18	17	7	7	30	54	5	19
h	17	17	18	15	8	4	4	50	54	4	55

*Masters' Ratings: 1. Ability 2. Attainment 3. Orientation 4. Confidence

TABLE I

(Continued)

	First Post Test	Second Post Test		Third Post Test			
				Slow		Fast	
	Time	Time	Neg	Time	Neg	Time	Neg
A	5:10	4:36	57	11:05	63	3:28	48
B	5:19	4:44	19	9:50	54	5:44	52
C	3:59	6:58	84	11:29	77	3:59	54
D	6:03	6:20	72	18:57	79	3:40	29
E	6:47	6:41	74	11:00	60	5:00	60
F	5:30	4:48	64	8:25	52	4:55	46
G	15:15	9:32	77	14:20	90	5:45	71
H	8:44	7:58	88	18:44	79	10:39	80
a	3:42	4:58	65	8:33	65	3:52	58
b	4:39	5:37	52	7:15	42	4:50	52
c	4:30	6:06	68	9:07	67	4:00	66
d	3:35	4:47	50	6:40	54	2:55	54
e	5:37	3:50	32	6:28	53	4:00	38
f	3:35	3:52	48	5:38	62	3:58	68
g	5:03	4:31	63	5:40	50	3:24	58
h	4:17	4:45	63	6:45	56	4:05	60

TABLE I

(Continued)

	Fourth Post Test				Boys' Ratings of Aids
	Time	Neg	Det	Pooled	
A	6:20	53	66	59.5	5
B	4:37	40	50	45	8
C	5:33	74	75	74.5	9
D	5:00	79	69	74	9
E	6:05	75	75	75	9
F	5:23	38	53	45.5	8
G	8:37	88	81	84.5	8
H	8:02	69	72	70.5	9
a	5:00	84	83	83.5	
b	4:20	69	69	69	
c	7:52	72	81	76.5	
d	4:09	78	72	75	
e	4:23	59	47	53	
f	4:12	80	72	76	
g	3:43	69	63	66	
h	4:08	70	66	68	

The Second, Third and Fourth Post Tests

These three tests all took place on the College athletics ground, and care was taken to obtain usable counts of obstacle negotiation. In all other respects, however, they were different and are not comparable with one another. We have therefore on the whole to take the results of each test by itself and obtain our experimental control by a comparison between our two groups.

The pairing of the boys was not close enough for us to take advantage of the more efficient statistical treatment of two accurately matched groups, as can be done for instance with twins or littermates, in which each member of a pair is compared with the other. Instead we have to compare the groups as a whole, the two groups being very reasonably matched in as many respects as possible.

The relation between the count of obstacles negotiated and the time for the course in these three tests is shown in diagrams 1 through 6. Diagram 1 shows the second post test results and it will be seen that the cluster of points appears to lie about a single straight line which represents the exchange rate between higher speed and better negotiation score. The boys of the control group tend to the faster but less accurate end of this line, the aided boys to the other.

This suggests that the effect of the aid is to cause the boys to go more slowly and carefully, but not to give them any extra help. If the control group could be given verbal or other encouragement also to be more careful and to take as much extra time for this as they need, then the difference between the groups would vanish.

Alternatively, if such instruction did not bring about a proportionate reduction in the number of failures to detect an obstacle in spite of greater time being taken, then this suggestion from Diagram 1 would be illusory.

The general instruction for the second post test had been to concentrate on avoiding obstacles and not to worry unduly about the time taken. The boys pointed out that this was rather unnatural for them, as normally they were more interested in making their journey than in avoiding bumping into a few things on the way.

For these two reasons, the next obstacle course, the third post test, was taken twice. The first time the boys were asked primarily to be careful to avoid the obstacles, and the second time to concentrate on speed. The results are shown in Diagrams 2 and 3. The instructions were effective in producing a slower performance for the first than the second time around yet the control

group did not, by taking more time, markedly improve their performance at negotiation. However with one exception the aided boys obtained as low a negotiation score on their fast trial as did the control boys.

In the fourth post test, whose results are shown in Diagram 4 (means of negotiation and detection scores), we again used the compromise instruction with regard to speed, but this time an attempt was made to separate obstacle "detection" and "negotiation," these being counted by different experimenters. Diagram 6 shows the comparison of the two scores. We tried rather to exaggerate the distinction between these two aspects, so that for instance some obstacles were successfully "negotiated" which had not previously been "detected." Nevertheless there was good agreement between the two scores.

Diagram 5 shows the comparison of these two scores when each obstacle of this fourth post test was taken by itself, but the scores are summed for the aided and the control groups separately. From this it appears that detection was rather better by the aided boys, and negotiation by the controls.

Table II lists the ten obstacles which were common to all three obstacle courses, although there were of course differences in the order and setting, and some were different in detail. It should be noted that here the score for the third post test is that obtained under the "careful" instructions, and for the fourth post test it is again the mean of negotiation and detection. The table shows five points:

1. The aided boys showed little difference in negotiation score among the three tests.

2. In contrast the control boys appear to have improved considerably in this score; nine out of the ten obstacles showed this improvement compared with five out of ten with the aided boys.

3. In the third post test, the second obstacle course, our artificial noise was switched on as the boys approached the "Thick Forest." The control boys showed a marked reduction in score for this obstacle on this test.

4. The aided boys showed no such reduction in score.

5. The noise was switched off when the boy left the Thick Forest and before he reached the next obstacle which in this case was the "Gallows." This also showed a localized drop in score suggesting that the disorienting effect of the noise had some aftereffect.

Finally, the first two of the points just listed are taken

TABLE II

SCORES PER OBSTACLE OF THE 10 OBSTACLES
MORE OR LESS COMMON TO ALL COURSES

Post Test Scores

	Aided			Unaided		
Obstacle	Second	Third	Fourth	Second	Third	Fourth
Deflector	75.0	100.0	97.0	63.0	100.0	100.0
Bicycle	75.0	64.0	65.5	44.0	50.0	72.0
Pin Wheel	19.0	67.0	53.5	63.0	64.0	100.0
Thin Forest	56.0	75.0	81.5	6.0	25.0	72.0
Thick Forest	88.0	63.0	78.5	63.0	19.0*	75.5
Waste Basket	81.0	81.0	50.0	58.0	56.0	66.5
T.C.Chicane	75.0	94.0	87.5	56.0	100.0	94.0
Gallows	63.0	44.0	47.0	75.0	25.0**	69.0
Step-Up	56.0	38.0	53.0	6.0	63.0	78.5
Step-Down	63.0	88.0	78.0	44.0	69.0	62.5

* Noise

** The obstacle immediately after noise

up by plotting the whole negotiation scores for these three tests as a learning curve (Diagram 7). Because, as has been stated, the three tests as well as the measures are not directly comparable, a curve such as this for either group of boys would be meaningless. But the two groups of boys can be compared, and thus we see that either the control group became considerably more skillful at negotiating our obstacles, or the courses became considerably

easier. In this latter case the aided group of boys must have become correspondingly less skillful. It might be said that we were in a position to use our increasing experience of obstacle courses and deliberately to make a course which would favor the control boys, but this we would stoutly deny. Our clinical impression agrees with the first possibility; namely, that the courses remained roughly comparable in difficulty, that the aided boys also had reached some constant level of performance, but that the control boys had become increasingly sophisticated in dealing with our obstacle situations.

Psychophysical Test

The purpose of this artificial test was to find out how accurately the boys could compare distances, using the aid, then they were given the best conditions which could conveniently be devised for doing so, free of time stress, anxiety about movement, or more than one echo to interpret at a time.

The details of what was done are given in Appendix B. In brief, a brick wall at a distance of 54 inches was given as the standard, and a thick fiber jumping mat which gave a very weak echo was judged equally distant when it was 50.2 inches from the torch. A wooden trolley covered with a double layer of sacking was judged equally distant at 53.1 inches and a small tree branch at 51.1 inches. These figures are average values obtained from seven of the boys. The eighth was not available because of illness.

Although this accuracy is remarkably good, there is a consistent tendency for test objects, all of which gave weaker signals than the wall, to be judged equally distant when in fact they are rather nearer. Thus there is some confusion between pitch and loudness of echo. This was marked in the case of two boys. One stated that although the echoes were of different pitch, he made his judgment as a compromise between pitch and loudness, and his error was 15 inches; the other boy said he could not match distances when the echoes were so different and asked whether he should take account of loudness of pitch. When instructed about this his judgments were as accurate as the others.

For comparison four control boys were tried in this situation, and although they complained loudly that they couldn't hear the jumping mat and one made no attempt, the other three produced a mean estimate of 48.5 inches. With the sack-covered trolley their estimate was 46 inches.

The Boys' Opinions

One of the eight boys gave the aid an indifferent rating, the

others all gave either 8 or 9, and there was no doubt that these seven were sorry to have to part with the aid at the end of the experiment. Six boys showed the aid to their relatives at the school speech day.

The boys of the control group were given the opportunity at the end of the trial to try an aid in the streets of Worcester, and they all expressed moderate or marked enthusiasm.

The Street Circuit

The results of the town trial are almost entirely subjective. The time taken for a set street route proved to have no practical value because for one thing we could not control for traffic density. Otherwise we have the film record of all the boys passing the same place, and we hope to show this to a number of independent judges.

Our impression was that the aided boys were on the whole slightly better in planning their course along the pavement, maintaining a constant distance from buildings or curb, and in anticipating obstacles. One boy who used the aid well was visibly helped by it in loud traffic noise.

Boys with the aid were willing to try, and to an extent they succeeded in doing, things which they could not do unaided. For example we took several boys through the bays of a large department store, and aided boys were here better than controls. Again, as an exercise the boys would pick out, say, the third of a line of cars parked close together.

Some of the younger boys in both groups hadn't been alone in the town center before and of these one in the control group became remarkably good at maintaining a steady course.

Finally, the fact of carrying the aid distinguished the boys at once, and people approaching would keep out of their way and sometimes try to offer "help." This sort of help was less available to the control boys some of whom looked and behaved as though they were sighted, and it made valid comparisons difficult for us.

Discussion of the Worcester Experiment

This part of the trial gave us experience of the aid under favorable circumstances. We had willing, disciplined, and intelligent subjects and reasonably controlled conditions. Without this background the subsequent trial at Ovingdean would have been extremely difficult.

Perhaps the most definite finding in favor of the aid was

that after more than eight weeks experience the boys would have liked to continue with its use. As far as we know this is the only recorded instance of this; most other aids tried have been discarded sooner rather than later.

These aids were prototypes and had many defects both trivial and important, most of which became apparent at an early stage. Probably the most important of them was that the wire leads very readily became tangled, and a minor tangle is a major inconvenience to a blind person. This and other defects (3) would be expected both to bias the boys against the aids and to reduce the measureable benefit of their use. It is likely that the novelty value of carrying an instrument resembling a miniature radar set partly outweighed the inconvenience of the tangling wires.

Several definite conclusions may be drawn from the performance tests. The aid did enable boys to do things which they would not otherwise have done, especially at first, for example, the location of narrow gaps and the detection of obstacles in the presence of noise which it was safe to ignore. The price of this achievement was an increase in time taken, sometimes by as much as a factor of two or three.

We are convinced, however, that many of these new things could be taught to unaided blind boys if we knew how to do it. Although the aided boys received more training during the period of the trial, it was the control group who made the greater improvement in terms of number of obstacles negotiated on our courses. We are sure also that with the aid, or with an unaided boy using his own sense of hearing, this improvement in range of tasks which can be attempted is brought about by an increase in the boy's perceptive range.

The amount and kind of training desirable with these aids has been under discussion since the trials were projected and is still uncertain. It was at first planned to hold fortnightly tests and between these to leave the boys mainly to their own devices except for weekly day visits (largely for encouragement). After the second post test, however, we became convinced that the trial would stagnate without increased training effort, and therefore one or more of us spent several days each week at the College. We must admit that we have no direct measure to show whether this effort was well spent. It is certain that our training could be greatly improved, and it may be that we succeeded only in maintaining the boys' own efforts and interest.

From our observations we would say that the aid was of much more help in detecting obstacles than in negotiating them. It is out of place here to discuss what kinds of information could or should be made available in an aid of this type. But it is also clear that this present aid can be used in different ways. We think the boys used it mainly to tell them whether their forward

path was clear or not. When asked to stop and look they could also deduce various items of information about an obstacle; for example, (a) its range, (b) its size and geometry, and (c) the nature of its surface. We have little doubt that our subjects could obtain the whole of this range of information, but that it took quite a lot of time and conscious effort. In an obstacle course or in Worcester's streets we doubt whether much of the information was obtained.

One source of confusion results from the wide range of loudness obtained in practice from different kinds of reflecting surfaces and from different angles of incidence upon surfaces which reflect in a specular way. A boy walking steadily along a row of shops would suddenly stop or swerve as though he had detected a close obstacle which in fact was not there. This we realized was due to a sudden increase in the loudness of the echo signal even though there was no change in pitch, resulting from the beam striking a projection or passing through normal incidence upon a shop window or car panel. The psychophysical test showed that, given time, loudness and pitch could be correctly sorted out. A further confusion which became apparent to us only at a late state was that due to the Doppler effect. The echo from, for example, a rapidly approaching pedestrian at very short range would correspond in frequency to a stationary object at long range. Thus conversely the sudden loud echo from a distant shop front could come from a pedestrian about to collide with a boy.

This situation of a rapidly approaching pedestrian was the only one in the whole trial in which our subjects showed any real signs of fear. We deliberately produced this situation in training, ourselves walking quickly up to our subjects and keeping well within the beam of the torch. The boys were told to swerve to avoid us at the last moment they judged safe. At first every subject had difficulty in judging when to step sideways out of our way although the signal from the aid was loud and clear. After a variable number of trials they learned to do this in the training situation, but only two or three boys were able to make use of this training when the situation arose incidentally during the street courses. These appeared to be able to do this only at the cost of slowing down and thus reducing their closing speed with the moving obstacle on the pavement. Boys of the control group, in traffic, usually appeared to have no knowledge of moving or stationary pedestrians and were undisturbed by colliding quite frequently with them. We were interested to observe how frequently this seemed to happen among sighted people in a moderately dense crowd of shoppers.

In summary, by the time the Worcester experiment was brought to an end by the approach of school examinations the boys in the aided group had learned to make appreciable use of their aids as long as there was time for them to do so. They liked the aid and

would have continued to use it. At the same time, the boys in the control group had undoubtedly also learned a good deal.

THE OVINGDEAN EXPERIMENT

This part of the trial is a complete contrast to the Worcester experiment in almost every respect. It was felt that the most important single question to ask was not whether this or that task could be done with or without the aid, but simply whether the aid would be accepted and used at all. It was clear from our Worcester experience that training was necessary, yet we wanted to find out whether the aid would be used when the subjects were left alone. It was equally clear from the beginning that a controlled trial similar to that at Worcester would be impracticable and we planned therefore to give our subjects as much training as we could for three weeks, and then to leave them alone for some four or five weeks with no more interference than that needed to maintain the aids in working order (I, pp. 154ff). On our return at the end of this time we would see whether any subjects had dropped out, and observe the performance of those who remained.

The Subjects at Ovingdean

Since a large proportion of St. Dunstan's men are of middle age or over we asked for volunteers of this age range, otherwise requiring only that they had no more vision than perception of light, that they be mobile, and had the use of both hands.

Ovingdean is a training and holiday center with accommodation for 120 men of whom about 40 are permanently resident there. Our subjects had to be drawn from the residents as the others were not continuously available for the two months of our trial. We had 11 subjects in all ranging in age from thirty-seven to seventy-three years, and 6 of these stayed with us for a reasonable amount of training. Four were left to carry on after the three weeks training period and on our return after a further five weeks 2 remained.

Of the nine men who dropped out, one did so because of age, one because of chronic asthma, two because of acute illness. The other five, after varying amounts of training, did not wish to continue. This summary is given here as an indication of the type of population we had available; i.e., men who through illness or age lived permanently at St. Dunstan's.

In the following comments about our subjects we assume that for the purpose of our discussion they are typical of the whole St. Dunstan's population. First, they had all been sighted until adult life and therefore they could talk in visual terms and

understand visual explanations. Second, most of them were accustomed to the use of a cane or stick although they had not received formal training in its use. Third, they were all of an age at which the acquisition of new skills is likely to need time and special training methods.

Fourth, we had the impression that these men did not mind being identified as blind, that they expected and accepted the help of sighted people. One of our subjects expressed a desire to be as independent of help as possible. For the others mobility meant the ability to traverse quite a small number of well known routes; this may also be the case with many sighted people.

These points suggest that the motivation to become proficient with the aid was not very high, and we consider that to have four men remaining after the training period was not quite as many as we could expect.

The Tasks Used at Ovingdean

Introductory Circuit

For the eight subjects who were available on the first day of the experiment we made use of a small public park and playing area. The subjects were first asked to walk along a path and up some steps, and finally around a lamp post, without the aid, and this was filmed. They were then given their aid and instructed in its use by following the contours of hedges, avoiding park benches, and so on.

Pearson House Area

Pearson House, the original St. Dunstan's home in Brighton, is situated very well for early training because it was possible to take subjects from there along routes differing in complexity and traffic load. This is an important facility early in training and with subjects differing so widely among themselves as those at Ovingdean.

Town Center Area

Here we generally started at the junction of East Street and North Street, moving either through heavy pedestrian and vehicular traffic or through a pedestrian shopping precinct known as the Lanes. Subjects encountered very dense and close pedestrian traffic without running any risk from cars and lorries. A further advantage of the Lanes was that they consist of a conglomeration of narrow alleys differing in width; this enabled us to try to teach the subjects the concept of maintaining a middle course between the two walls.

Results of Ovingdean Experiment

The Men who Stayed the Course

Of the two men whom we were able to observe and question on the last day one was celebrating his sixty-first birthday on that day, and the other was forty-nine years old. The former was blinded as a result of detached retinas, the other as a result of a booby trap explosion in 1942.

The sixty-one year old, when being taken through a street circuit near Pearson House, produced a moderately good performance, using the aid for very close work, i.e., 3 to 4 feet at the most.

In his comments this subject stated that while he thought the aid a good thing he, in effect, was too old to learn how to use it and he preferred the cane. He found it hard to hear the changes in pitch when encountering any degree of traffic and appeared to work largely on loudness changes.

The forty-nine year-old man had been one of the original group of eight, but owing to the presence of his children at Brighton during the training phase, he had in fact received the least amount of formal training. He claimed to have practiced a great great deal by himself and with the aid of his children. We examined him very carefully both in the Lanes and along a walk below the cliffs at Ovingdean because he told us that he had found the aid most useful there. We found him to be almost completely devoid of any ability in the use of the aid, but the only one of our men who showed anything like the obstacle sense of the boys at Worcester. When we asked him to switch off the aid he showed a remarkable ability to follow the contours of the cliffs along this walk, which was admittedly a very familiar one to him.

This man was very enthusiastic about the aid and was sorry to have to give it up. His comments showed that he had strong personal reasons for wanting to be independent in his mobility. We formed the conclusion that this subject's comments with regard to the aid were unreliable.

The Men who Persisted in Training

There were two further men, aged forty-three and sixty-six, who remained with us until the end of the training period but could not continue because of acute ill-health.

The older man was a fine example of persistent cooperation even though he found it hard to move about in any case and harder still to grasp the information presented by the aid. This subject stated that he would not have continued to use the aid for

his own purposes.

The younger of these two men made good progress and was willing to place the aid on a par with his stick. In the course of an interview at the end of the experiment, and when he had been without an aid for some five weeks, he said he would have carried on with the aid but he preferred the stick because it gave him more direct information about the things he was about to encounter.

The Men who Dropped Out During Training

Four men dropped out during the first week. One, a man of over seventy, said that he was too old, another aged sixty-five was keen and enthusiastic but had to stop because of his asthma. Of the other two who were both some twenty years younger, one dropped out because the noise from the aid made him nervous and the other because he was just settling down to a solid course in braille and could not spare the time. This man's reaction is of some interest since he was only recently totally blind and a man of some intelligence.

Three men dropped out during the latter stages of training. One of them appeared to make quite good progress until he was discouraged by a fall. The other two men simply found the problem of learning to cope with the aid too much.

General Opinions Expressed

It is worth recording that the majority of the men who used the aid at any time at Ovingdean gave favorable opinions, i.e., they thought the aid was a "good thing" even if they did not carry on using it.

Discussion of the Ovingdean Experiment

In the light of the account presented the reader may feel that one should either write off the Ovingdean experiment entirely or not attach too much importance to it. It would be quite wrong to do this for two reasons: first, the experimenters gained a great deal of insight from the comparison between the boys at Worcester and the men at Ovingdean. Second, it is rather difficult to see how one could evaluate an aid, or indeed any other system, more adequately at Ovingdean under prevailing conditions. From this point of view we may say that acceptance of the aid was put to a very stringent test indeed at Ovingdean because the conditions were such that anybody was completely free to withdraw from the experiment whenever he felt like it. The following remarks must be considered against this background.

The acceptance rate of the aid by the men at Ovingdean was not very high: two out of eleven men retained the aid to the end,

and one of them would have wanted to keep it. If we add the one good subject who stayed with us right through training but had to drop out because of acute illness this still only leaves us with a rate of two out of eleven. That is the picture as far as voluntary continued use of the aid is concerned, and it is by this, rather than by opinions expressed, that we have to judge acceptance.

So far the matter is simple. It is quite a different matter to be certain why the aid was acceptable to two men only. There were certainly a number of features which operated against acceptance by that particular group of men: there were three men to whom, because of age and infirmity, the aid could not have been of any help; since they had been included in the group we had to try our best with them. For a variety of reasons the men were not very highly motivated towards trying out the aid; even among those who stayed with us longest there was a fair amount of casual absenteeism.

Our training procedure may have been inadequate. It is quite possible that a different approach might have produced a higher acceptance rate. There were of course major differences between the subjects we had at Worcester and at Ovingdean; we certainly did not feel that we could make anything like the same demands of the men and we had to adjust to the fact that they had been sighted until at least early manhood.

The aids were not sufficiently reliable technically. It is difficult to say whether the aids had deteriorated since Worcester, or whether the boys were less upset by minor malfunction, or whether the reliability problem at Worcester had been only apparently less because of Dr. Kay's constant readiness to deal with faults on the spot. The major technical difficulty encountered was a low signal/noise ratio and the not infrequent cessation of the signal altogether (3).

But when all the considerations of composition of the group, motivation, training, and reliability have been taken into account, there still remains the opinion of the experimenters: the low acceptance rate of the aid is probably a reasonably accurate index. There is little doubt in our minds that to make use of the aid requires a great deal of perseverance and not a little intelligence. And even when the aid is used to capacity it may not add significantly to the mobility of war-blinded men accustomed to negotiate their world by means of cane or sighted companion.

FINAL DISCUSSION

It seems proper to discuss our results from three points of view: first, in relation to the specific guiding aid under examination;

second, with regard to this particular system of echolocation; and finally in terms of aiding the mobility of the blind in general.

As far as the first point goes our answers are about as definite as one could hope them to be: the aid did most of what the designer said it could do, and the boys performed quite well with it and liked it, although boys given some very crude form of unaided mobility training did about as well; the men did poorly and did not persevere in the use of the aid, even though they expressed favorable opinions on it. We think, but do not know, that if one could give something like four weeks' intensive training to a group of intelligent youngsters they might do rather better than the Worcester boys. But it might take a good while to develop a suitable training scheme, and the same amount of effort put into unaided mobility training might well be equally rewarding. We are reasonably certain that training with the aid would not benefit an Ovingdean group to anything like the same extent, partly because they are rather less motivated to be independently mobile over unknown terrain. There are however other important differences between the two groups and they are worth bringing out again. The boys were younger, had been blind from birth or infancy for the most part, and appeared to possess "facial vision." The men were older and more set in their ways, had been sighted until early manhood at least, and appeared to rely on tactual cues far more than auditory ones. It is the last difference which is perhaps one of the most crucial from our point of view: the cane used as an extension of the sensing hand is essentially a near receptor while the ear, aided or unaided, is a distance receptor. The boys, we think, were able to make use of the aid not only, as we thought at one stage, because we managed to bridge the gap between the sensing hand and the sensing beam of the torch, but more importantly because they were accustomed to working on cues not too different in kind from the aid. The men like to have direct tactual contact with their immediate environment; the boys do not appear to have this need. This difference between the men and the boys may be more important than that the former can visualize a street scene and the latter cannot. There is perhaps only one aspect in which the existing mode of mobility control favors the men: since they do like to "keep in touch" with their environment they tend to give obstacles much less clearance than the boys are wont to do and might therefore sometimes walk closely around an obstacle which the boys would want to keep away from. The aid does enable a blind person to clear obstacles with very little tolerance and, in theory, estimates of clearance can be made accurately in advance of encountering the obstacle.

Turning now to the question of whether this particular form of echolocation (i.e., frequency modulation and presentation of range information in terms of pitch) is in general a promising system, we can only speculate since we did not have other systems to compare with Dr. Kay's. Leaving aside for the moment the constraint imposed by the narrow beam, it is of course true that much of the information apparently necessary for mobility is presented to the ear

by means of the aid; but it has to be translated by the listener, there is rather a lot of information to be dealt with, and the information presentation is sometimes opposed to normal expectation and perceptually ambiguous. It is the third point which we wish to draw attention to because the conflict between loudness and pitch turned out to be one of the major difficulties encountered in teaching people the use of the aid. More generally it seems worth pointing out that there are plenty of instances in the literature where a reduction in the amount of information presented has produced better human performance; it is the rate at which information can be handled which matters rather more than the wealth of information available. If further work on echolocating systems of this kind is contemplated one would hope to be able to control complexity of sounds during training.

Turning at last to the general problem of aiding the mobility of the blind we can now pick up the comments made in the Introduction to this report. We were woefully lacking in basic information concerning all aspects of the mobility of the blind. To reiterate only one point, we did not know then just how well blind people can do without any aid and as far as we know there is in fact no measure of that ability. We think the time has come for a comprehensive research program concerning the mobility of the blind to be undertaken in this country. One result of such a program should be the possibility to specify rather more closely just what any form of aiding should achieve to make what sort of a contribution to what size and type of population of blind people.

To conclude this discussion we would like to point out that the problem of providing the blind with aids to their mobility is in principle no different from that of providing a pilot with efficient instrumentation: it is a man-machine system problem for which there may be a range of possible solutions. In adopting any one solution one has to weigh up many factors and compromise between what may be ideally desirable and that which can be achieved with the resources at one's disposal. It is presumably ideally desirable to replace in some manner the sense of vision for the blind. What we have to consider, however, is what means there are at our disposal to narrow a gap rather than to fill it in. At the moment we are only very little better off than Dr. Beurle was some ten years ago when he summarized his reasons for the failure of acoustic blind aids. Given that we want to make a significant contribution towards the increased mobility of the blind, is the all-around effort required to make acoustic guiding aids worth the likely outcome, or would it be more worthwhile to concentrate on other forms of mobility training? We submit that at present such questions cannot be answered for lack of data.

In the meantime, there is of course no reason at all why

work on developing echolocating systems for human use should not be continued by the engineers. It is clearly essential to know what kind of hardware is practicable, how much and what kind of information it can present, and how reliably it can be produced. But even here a word of caution seems indicated. The engineers can provide us with a system which is very good from the engineers' point of view in that it displays all the information thought necessary by the engineer and in that it can be controlled in engineering terms. But it may not be possible for the average blind man to make use of the equipment, or it may only be possible for him to do so after a fair amount of well-worked-out training. What this amounts to is that the engineer in his laboratory may not be able to assess the usefulness of his equipment by himself, and he may run one of two risks: either he may reject a system which given adequate training might have been useful, or he may overestimate the usefulness of his equipment for lack of knowledge of how little his equipment helps the blind.

Finally, in this work we have tried to answer a specific question. We believe we have done so, in a limited sense; but before further progress can be made, very much more general information on the mobility of the blind will have to be obtained.

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

We demonstrated to our satisfaction that the aid is capable of what was claimed for it and we consider that this is a considerable achievement.

We have shown that the aid could be used and was acceptable to the majority of a group of highly intelligent boys, most of whom had been blind since infancy or at birth.

We have also shown that the aid was not acceptable to the majority of a group of men from St. Dunstan's, Ovingdean, and we are satisfied that only one of that group showed any sign of being able to make use of the aid.

We strongly recommend that before any further work on the development of acoustic blind aids is undertaken the mobility needs and requirements of the potential users of the aid be investigated, and that specifications for acoustic aids be considered in relation to the results of such an investigation.

We also recommend that the performance capabilities of acoustic aids be considered in relation to other aids, such as the cane or the guide dog.

There are at least two glaring gaps in the work reported on: we never left any subject more or less entirely to his own devices and we were not able to examine the recently blinded.

If any further work with the present aid should be carried out on such populations we recommend that the reliability of the aids should be improved until they can be left unattended, except for a battery charge, for a period of three weeks at least.

APPENDIX A: A NOTE ON THE OBSTACLE COURSES

In this trial we made use of obstacle courses simply because of the need for an objective and reasonably consistent performance measure. They may not in fact be the best means either of training or testing but we saw no alternative.

At first we were helped by suggestions made by the boys themselves as to the obstacles they found difficult in practice, by a list of obstacles given in the Haskin's (1946) report, by a visit to the Leamington Training Center of the Guide Dogs for the Blind Association, and by the description of an obstacle course used in the Haskins Laboratory (4). From the start we set ourselves four objectives:

1) The obstacles and their settings should be as real as we could contrive.

2) The boys' performance should be scorable for both detection and avoidance. We later changed this to "negotiation" as being more comprehensive.

3) The course should extend the boys, in that they should know they might hurt themselves; but not, we hoped, too seriously.

4) The boys should find the courses enjoyable. This we found to depend somewhat upon point 3.

Obstacles and Settings

We were able to simulate or reproduce many of the obstacles named by the boys. Bricks and tea chests proved to be useful basic units for assembling different kinds of structure. The real difficulty is to link the obstacles together in a reasonable manner but in such a way that they were not simply by-passed. As Figures 7 through 12 (see pages 109 through 111) show we tried various means, from the walls and fences of the college to portable beech fencing and guide ropes. Of these the first is most realistic but too inflexible. The second is very laborious to set up and in practice proved very confusing for the aided boys because echoes from the beech stakes were unpredictable in loudness, depending upon the orientation of the stakes. The last was most flexible and easy but is unrealistic and the boys had to guide themselves along the rope by touching it.

Performance Scoring

We were not really satisfied with our scoring. As this depended mainly upon a subjective estimate the same experimenter had to score throughout except in the last course when two of us scored simultaneously. With the same exception the score obtained was a compromise between detection and negotiation. In general it was possible to say "yes" or "no" to each obstacle but sometimes a half mark was necessary. The method used in the last course of having two experimenters and scoring detection and negotiation separately was an improvement.

We did not interpret negotiation to mean passing an obstacle without touching it. Rather to the contrary, the boys were encouraged to make use of their normal methods of dealing with things including reaching out and touching them to make sure of their exact position or size, or feeling with the foot for the height of a step. In some cases the decision was easy as for example when a boy fell straight over an obstacle. At other times a decision was more difficult.

In spite of our efforts to avoid this there remained a few cases where a boy would walk past an obstacle giving no sign of having noticed it. In such cases the obstacle was left out of account in calculating a proportional score.

Finally, both aided and control boys occasionally appeared to detect some obstacle when none was present. We took no account of these "false" positives. An example of this may just be seen on the film of the third post test.

Course Difficulties

The boys bumped themselves or stumbled quite frequently, but in fact we had no casualties. The boys were remarkably good at coping with such situations. We might have made the courses harder, but we feel that the boys would have felt no challenge had they been made less difficult.

One index of the manner in which the courses were changed is that for the second post test we scored the boys at 28 points, for the third at 26, and for the fourth at 17 only. Some of these scoring points might relate to the same obstacle, i.e., a step-up and a step-down.

APPENDIX B:
PSYCHOPHYSICAL TEST

No attempt has been made to explore systematically the limits of target detection with the acoustic aid. Quantities such as the minimum diameter of circular rod which can be detected at a fixed distance under controlled conditions may be of value in comparing

aid designs, or as production tests in the manufacture of aids, but would be of little value in the present work.

This present controlled test of distance judgment was done because there appeared to be an ambiguity in interpretation of the received signals between loudness and pitch. Objectively the distance of a stationary target or obstacle is unambiguously indicated by the pitch of the received signal. Loudness on the other hand is a complicated function of size, orientation, surface texture, and distance and varies over a very wide range. Observation of our subjects suggested that loud signals were treated as important and indicated something which needed to be avoided even though a high pitch indicated that the obstacle was relatively distant. We therefore set up this psychophysical test to check whether, under ideal and necessarily artificial conditions, surfaces of widely differing reflectivity could be equated for distance.

The test was conducted in a bare garage building. A table was set up with one longer edge parallel to, and at a distance of 54 inches from, the unplastered brick rear wall of the garage. The subject sat in a chair facing in a direction parallel to this wall so that his right elbow and forearm holding the torch could rest on the table. The corner of the table was taken as the point of reference; the standard signal was obtained by aiming the torch, with front surface coincident with the table edge, across in front of the subject and normal to the wall. The variable signal was obtained by turning the torch through 90 degrees so that the front surface coincided with the table end and facing parallel to the wall. The variable target was place in front of the torch in this position, and consisted either of a 2-inch thick gymnastic jumping mat or a double layer of ordinary sackcloth thrown over the end of a laundry trolley with an open wooden frame. A third target consisted in a cut branch of a tree, bearing twigs and laves, mounted upright on a small wheelbarrow. This branch was some 3 feet in length and the leaves spread over a depth of about 18 inches. It was intended to represent a small bush and in practice produced echo signals with a spread of pitch corresponding to the spread of distance from the nearer and the farther leaves and twigs. In measurement the main branch was taken as giving an average distance.

At first each boy was asked to use whichever range setting of the aid he preferred for the standard target, i.e., the wall. The variable target was then presented at longer range, some 7 feet, and the subject was asked to assure himself that this was indeed more distant than the standard. The variable was then slowly moved in, and the boy was asked to say when the two targets appeared to him to be equidistant. This distance having been measured the target was moved farther in until it was judged to be distinguishably nearer than the standard. The target was

then moved out again until the distances were once more judged equal, and finally until the variable was distinguishably farther away.

Some of the more obvious faults in this extremely crude psychophysical design were commented upon by the subjects, but the way they did this showed that they were trying to make judgments and not to cheat. Thus it is felt that the results have some value as an estimate of this ability, although clearly one cannot make much of them.

It is also worthy of note - perhaps the most important finding of this little experiment - that the subjects were very slow in making their judgments. The torch would be moved a number of times between the standard and the variable targets before a judgment would be given. This tends to support our idea that although pitch is a sufficient cue to distance, it is not one which is obvious to the subject, and that some effort and concentration is needed to extract it.

Table III gives the results for 7 boys; the remaining boy was ill on the day of this test. One subject, No. 2, would not at first give an opinion on distance, saying that as the signals were so different in kind (meaning mainly, in loudness) comparison was unreasonable; however on being asked to base his judgment on pitch and disregard loudness, his results were then as accurate as the others. Note that at this time the aids had been in use for four weeks and we supposed this point to have already been learnt. One other subject, No. 3, had similar trouble and asked about it, but he was unable fully to allow for the intensity difference with the mat and the tree. It is unfortunate that no means was available to measure the echo amplitude from mat and from brick wall. As a rough estimate, however, when the aid was adjusted to produce a loud echo from the wall (say 80 db above threshold) the mat echo was difficult to distinguish above ambient noise, which was low (say some 30 db). It may well be that pitch comparison between signals which differ by 50 db is less good than between signals of comparable loudness, even under the best laboratory conditions, but the point is not known.

The Table shows that accuracy in this task under these conditions was remarkably high, being best with the sack which gave the strongest echo.

APPENDIX C: TECHNICAL POINTS

On the Use of the Range Switch Provided in the Aid

Our subjects differed widely in the use which they made of this facility and it was not possible to keep a record of this. The picture was further confused by the variability of ranges between

TABLE III

DISTANCE IN INCHES OF THE VARIABLE TARGETS

(Distance of Standard, 54 inches)

Subject	Thick Mat Nearer	Thick Mat Same	Thick Mat Farther	Thin Sack Nearer	Thin Sack Same	Thin Sack Farther	Tree Nearer	Tree Same	Tree Farther
1		49			55			57	
	45	51	55	54	54	60	51	56	60
2		51			52			52	
	40	52	60	46	52	62	36	52	60
3		40			53			44	
	31	37	46	42	53	59	39	43	54
4		49			53			54	
	46	54	55	49	50	57	50	58	59
5		53			55			43	
	45	54	55	51	52	55	34	44	51
6		54			54			52	
	49	53	55	52	54	56	47	52	54
7		53			53			54	
	51	53	55	51	54	56	50	54	61
Mean		50.2			53.1			51.1	

sets; there appeared to be a complete overlap, with the repetition rates for some sets' short range being as slow as the long range of others. Our impression, however, is that the long range was preferred.

On the Use of One or Two Earpieces

In the early stages of the trials the senior author decided that only one earpiece should be used. We were then quite definitely oriented towards allowing the boys to augment their ordinary cues and did not wish to risk casualties because of inability to perceive ordinary cues. The advantages of using two earpieces did not seem to outweigh the possible drawbacks. Subsequently however most boys were given two earpieces each. Difficulties in matching were largely overcome and some of the boys certainly preferred to use two earpieces some of the time. A true evaluation of the difference was not possible because part or whole of one channel might be out of action for several days during which the boy had to make use of one output only.

The Effect of External Noise on the Use of the Aid

Apart from the rather dramatic effect of noise shown earlier in Table II which showed the usefulness of the aid in the presence of external noise we did not investigate this systematically. We did have numerous comments on the effects of loud traffic noise, in which case the subject could either turn up the volume of the aid so that all other noise would be drowned, or he could allow the signal from the aid to be masked and therefore useless. We were naturally somewhat apprehensive of the boys stepping off the pavement and into traffic, so that on the whole we recommended stopping if the external noise became too great and there was any danger of getting hurt.

APPENDIX D:
THE CONCEPT OF PERCEPTUAL SPACE

People who are blind are clearly different from sighted persons because they are deprived of what is usually regarded as the most important of the distance senses. Those who are congenitally blind or who have been blind from early childhood as a consequence also lack visual imagery. Apart from this they may also differ along yet another dimension which we will call the extent of perceptual space. This is a concept which we are introducing to deal with some of the difficulties which we encountered when trying to train the boys at Worcester to make better use of the blind aid.

In so far as it is effective, this aid is of help to the blind in enabling them to be aware of objects at a greater distance than would otherwise be possible for them. We may say that their horizon is increased or their perceptual space extended. It

is therefore relevant to ask what the perceptual space of the sighted and of the blind is.

The first difficulty is that of definition. We have understood the term "perceptual space" to refer to that volume of space whose contents are at any time perceived by the subject, or which could be perceived if his attention is drawn to them, and which from moment to moment influence his behavior. Clearly this is a very indefinite quantity, and any boundary drawn may seem almost arbitrary.

However, the sighted person in moving about, has normally full knowledge of his near environment, and can look ahead as far as necessary. For example in walking along a not overcrowded place the sighted person takes account of whether his path is clear, and is likely to remain clear, perhaps for twenty to thirty feet ahead.

The sighted person in the dark is in a very difficult position, and we may be reasonably certain that his knowledge of his surroundings extends only as far as he can feel with his hands and feet. That is, his perceptual space has become a sphere with something like a two-foot radius.

This appears to be more or less the case with the blind, and in general it was confirmed by our experience in attempting to train these boys in the use of the aid. If their frame of reference extends in space only a few feet than an echo, on the aid, from an object beyond this is difficult to place. Nevertheless, a systematic search of the space before them with the aid should in theory enable them to extend these co-ordinates and to place a few objects therein, although we would expect this both to take an appreciable time, and to demand considerable effort on short term memory, reasoning, and imagination.

It appears very likely that if a person blind from birth is in fact as limited in his perceptual space as this, then it will be very difficult, perhaps impossible, to teach him to extend this space by using such an aid.

But of course sight is not the only distance receptor, and even a sighted person in the dark, who is not used to relying only on this sense, can perceive quite a lot about his environment through hearing supported by past experience and reasoning. The blind also use their sense of hearing, to a very variable extent, and we did not realize before starting this work how very proficient some of them could become. The term "facial vision" has been used to describe this very developed use of hearing. This makes our definition of perceptual space very difficult to apply, because localization of sources of sound in space is of necessity rather indefinite. The blind person with "facial vision" may be

aware of many things around him, but only very nebulously, and he may not be able to allow these nebulous perceptions directly to influence his movements or behavior until, by exploring with his hands, the various objects which he knew were there have been definitely located.

It is with blind people who have this ability that the best hope for successful use of aids such as this probably lies. They already have, and use, a wider frame of reference than their arms' span. The aid, by identifying objects and placing them on this frame of reference, would enable them to increase the space before them which can directly influence their behavior.

There are some immediate consequences from this line of argument. First, one would like to carry out experiments to establish the extent of perceptual space for sighted and blind persons. Second, if we are right in suggesting that the concept of perceptual space is a useful one, we might argue further that it is something similar to the "body image." This is a scheme which one is said to have of the position of one's body in space as well as relative to other objects in space. From this point of view it may well be that mobility training in the congenitally blind should start at the earliest possible moment so as to allow the building up of wider perceptual space.

ACKNOWLEDGMENTS

Throughout these trials we had the full help and cooperation of the designer of the aid and in several cases our procedures were modified as a result of his comments. It was he who made initial arrangements at the Worcester College for the Blind, and we wish to thank Dr. Kay for all this help.

Our thanks are due to the Headmaster, staff, and boys at Worcester College for the Blind and the Commandant, staff, and men at Ovingdean for providing the facilities to carry out the evaluation trials. We would also like to thank M. C. Jones and Dr. Gomulicki for much useful advice. Our thanks are also due to R. C. Newman, A. Tickner, and D. C. V. Simmonds of the Applied Psychology Research Unit. Most of the work reported on was carried out by members of the Medical Research Council's Applied Psychology Research Unit, Cambridge.

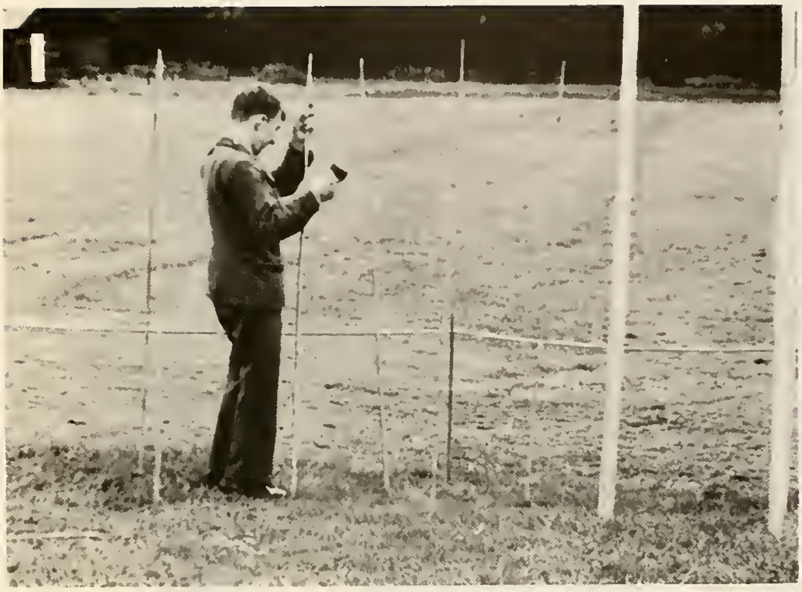


Figure 7. Example of obstacles: Thin Forest

Figure 8. Example of obstacles: Thick Forest

Figure 9. Example of obstacles: Narrow Gap

Figure 10. Example of obstacles: Tea Chest Chicane

Figure 11. Example of obstacles: Lock Brick Wall

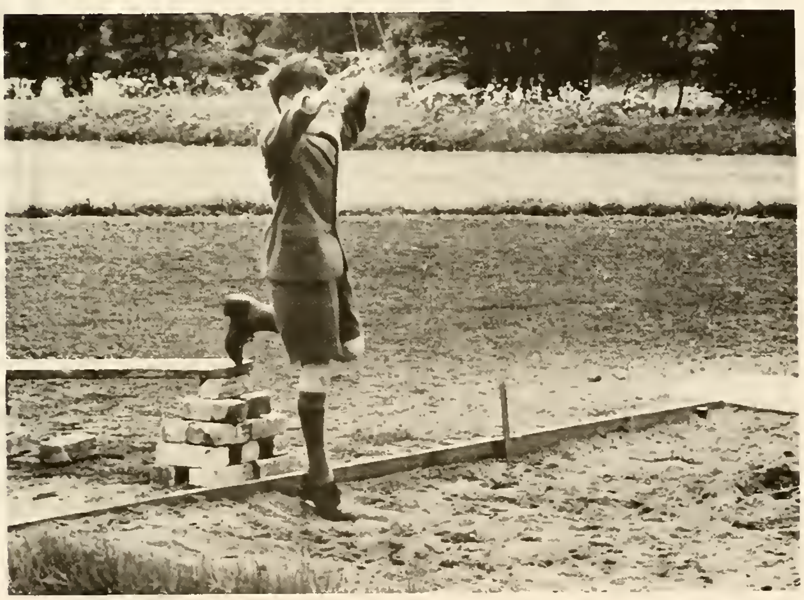


Figure 12. Example of obstacles: Step-Down.

1 ST OBSTACLE COURSE — 2 ND POST TEST

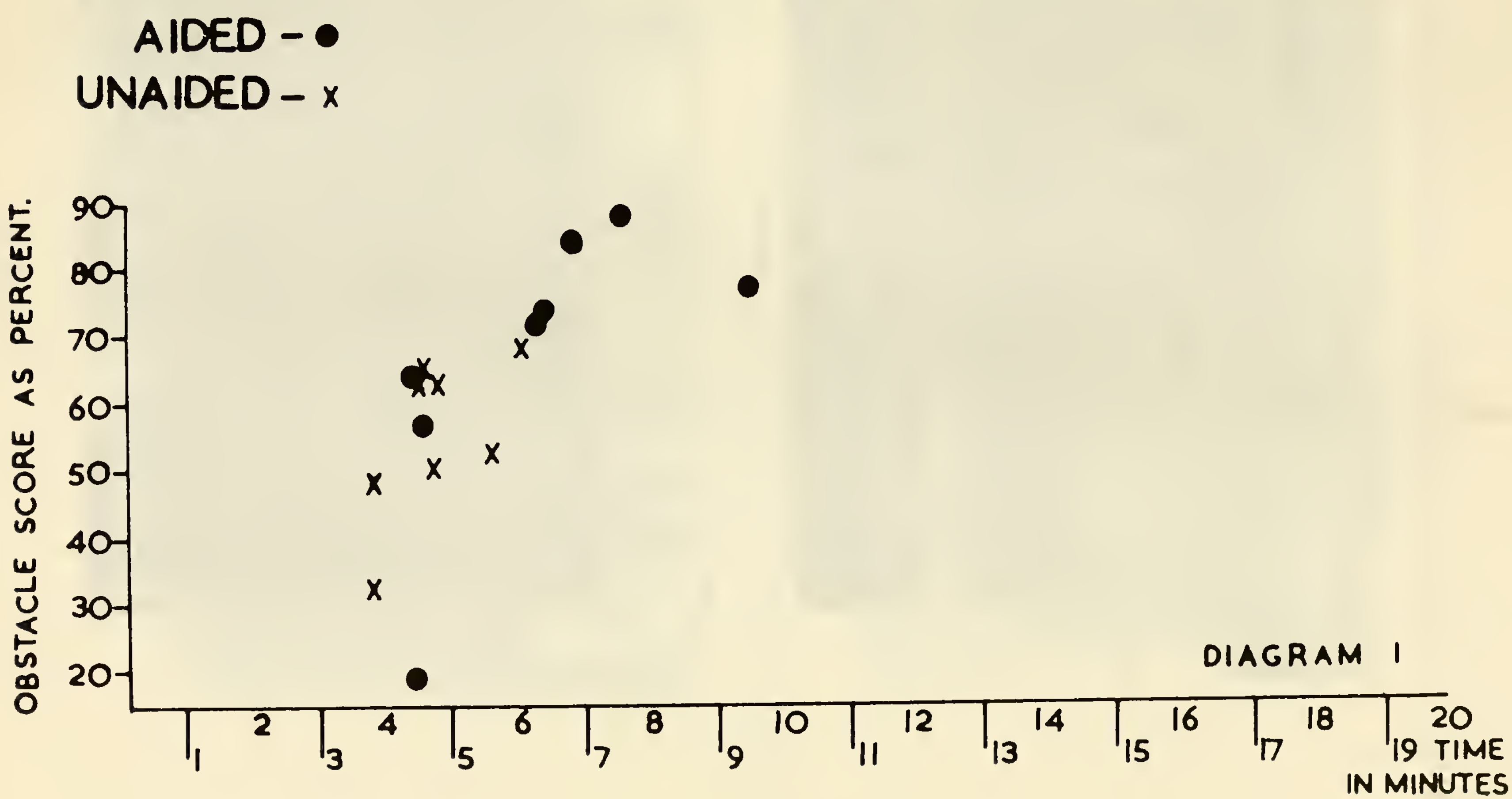


DIAGRAM 1

2ND OBSTACLE COURSE — 3RD POST TEST (SLOW)

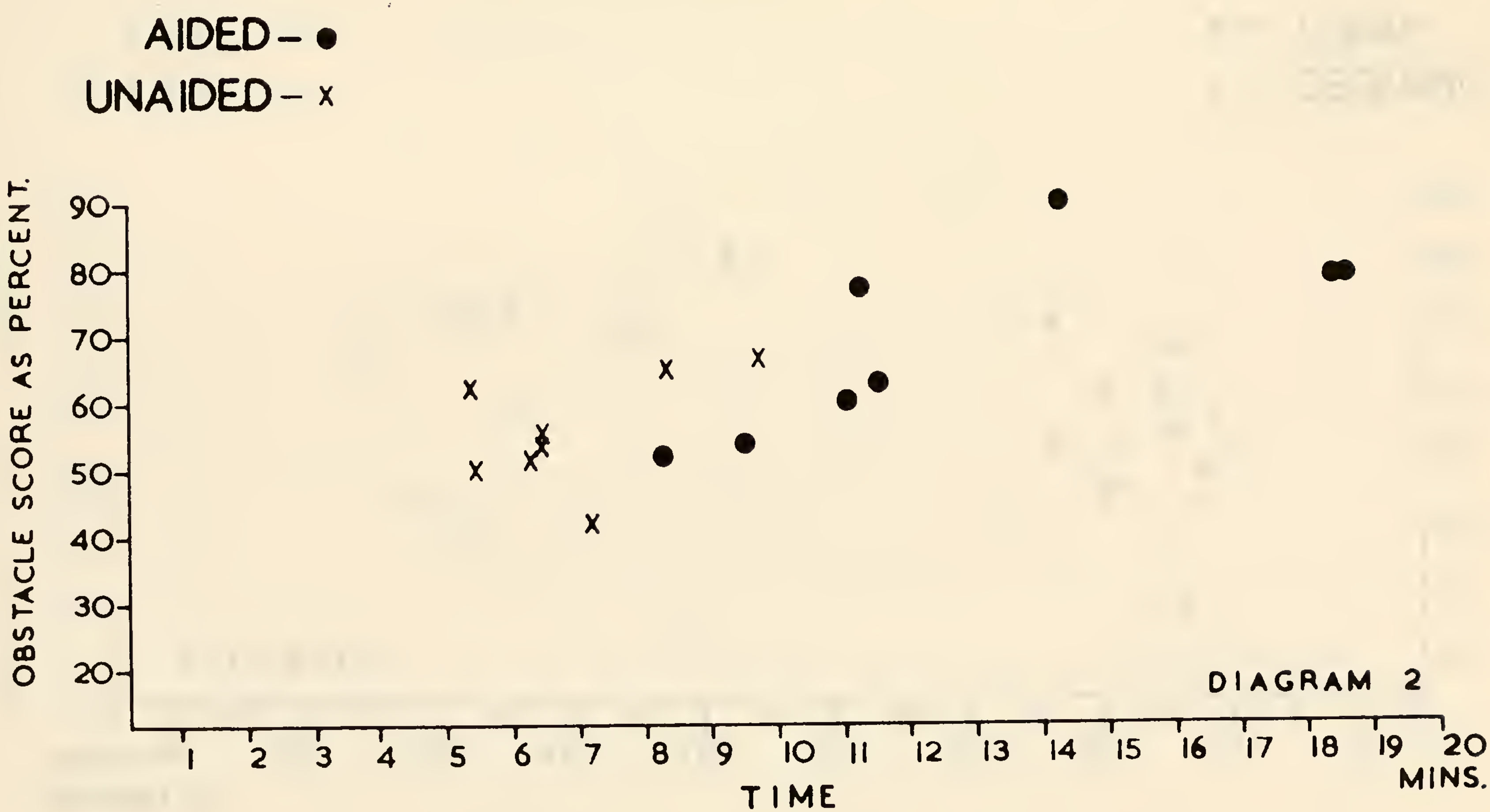


DIAGRAM 2

2 ND OBSTACLE COURSE—3RD POST TEST (FAST)

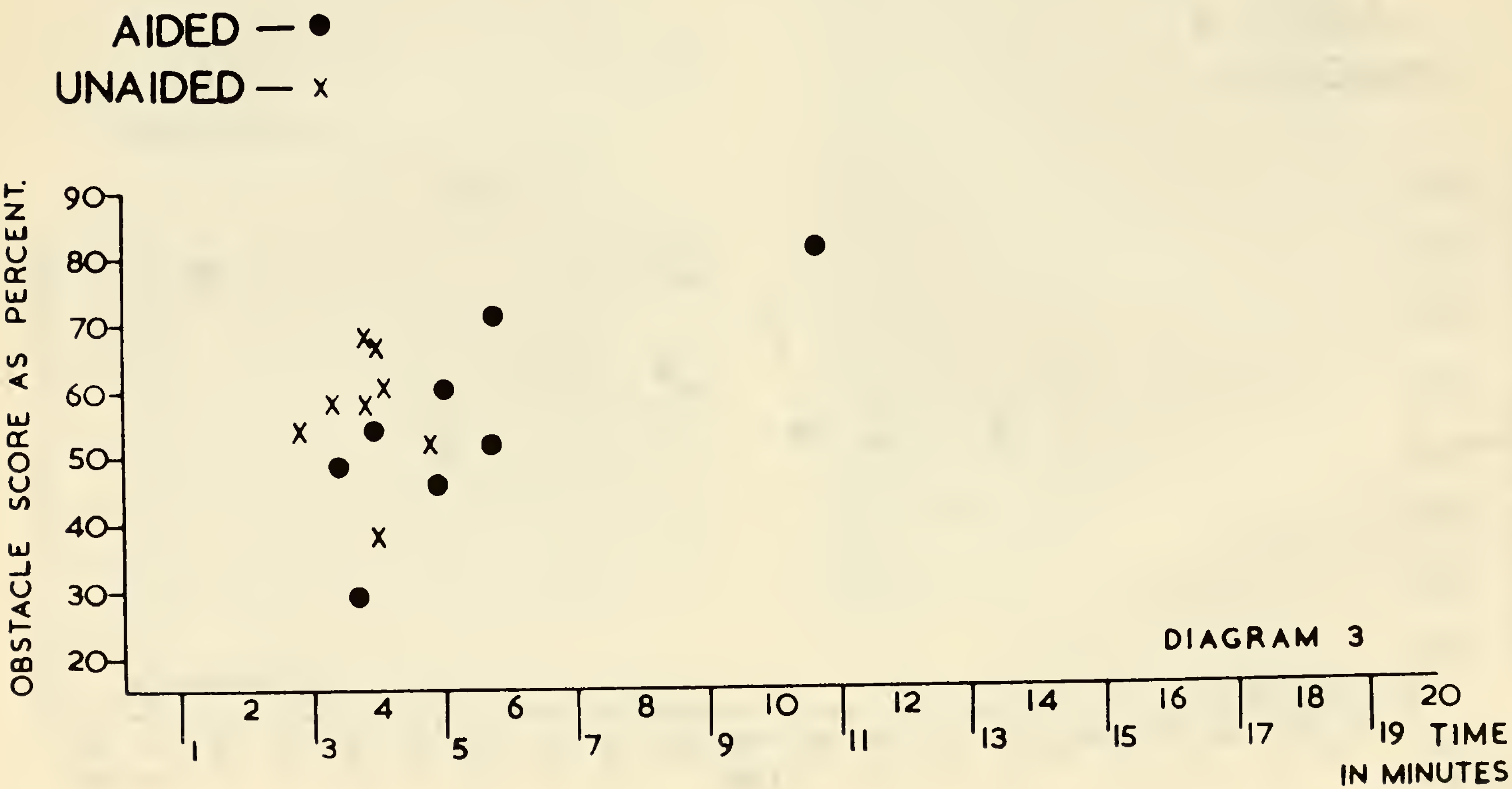
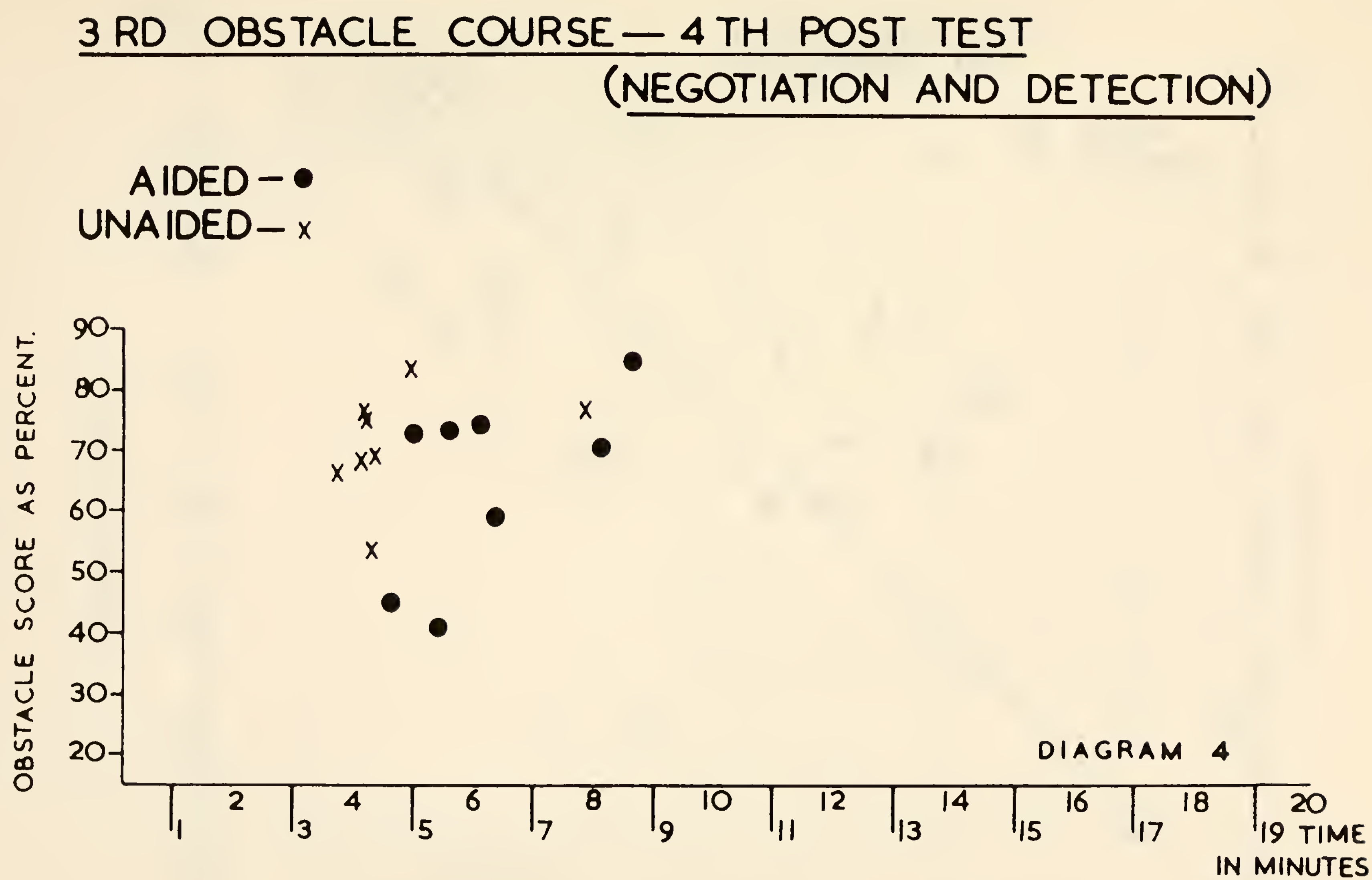


DIAGRAM 3



3 RD OBSTACLE COURSE — 4 TH POST TEST
(NEGOTIATION AND DETECTION)
AIDED — ●
UNAIDED — x
OBSTACLE SCORE AS PERCENT.
90
80
70
60
50
40
30
20
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
TIME IN MINUTES

DIAGRAM 4

4TH POST TEST (BY OBSTACLES)

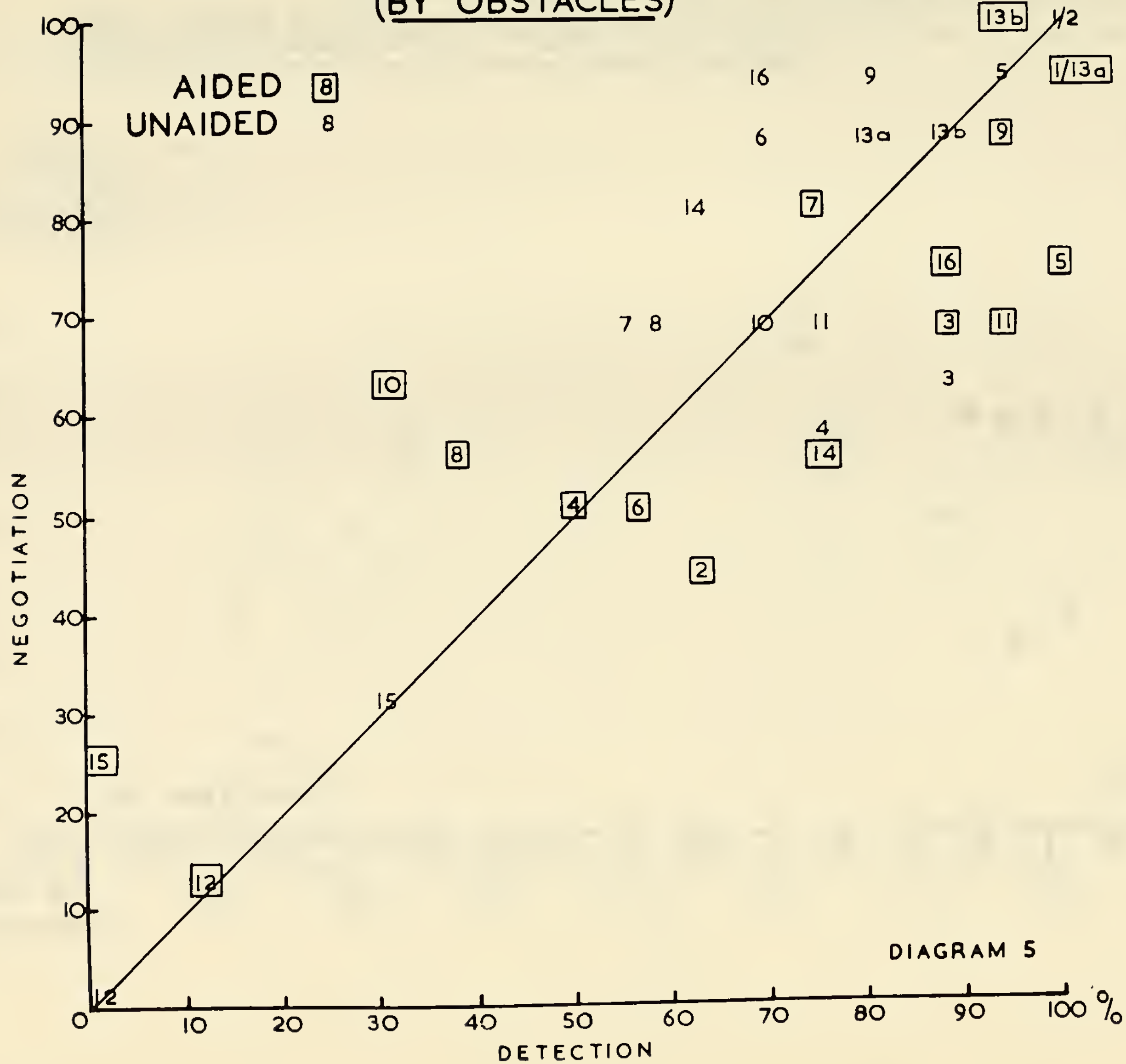


DIAGRAM 5

4TH POST TEST

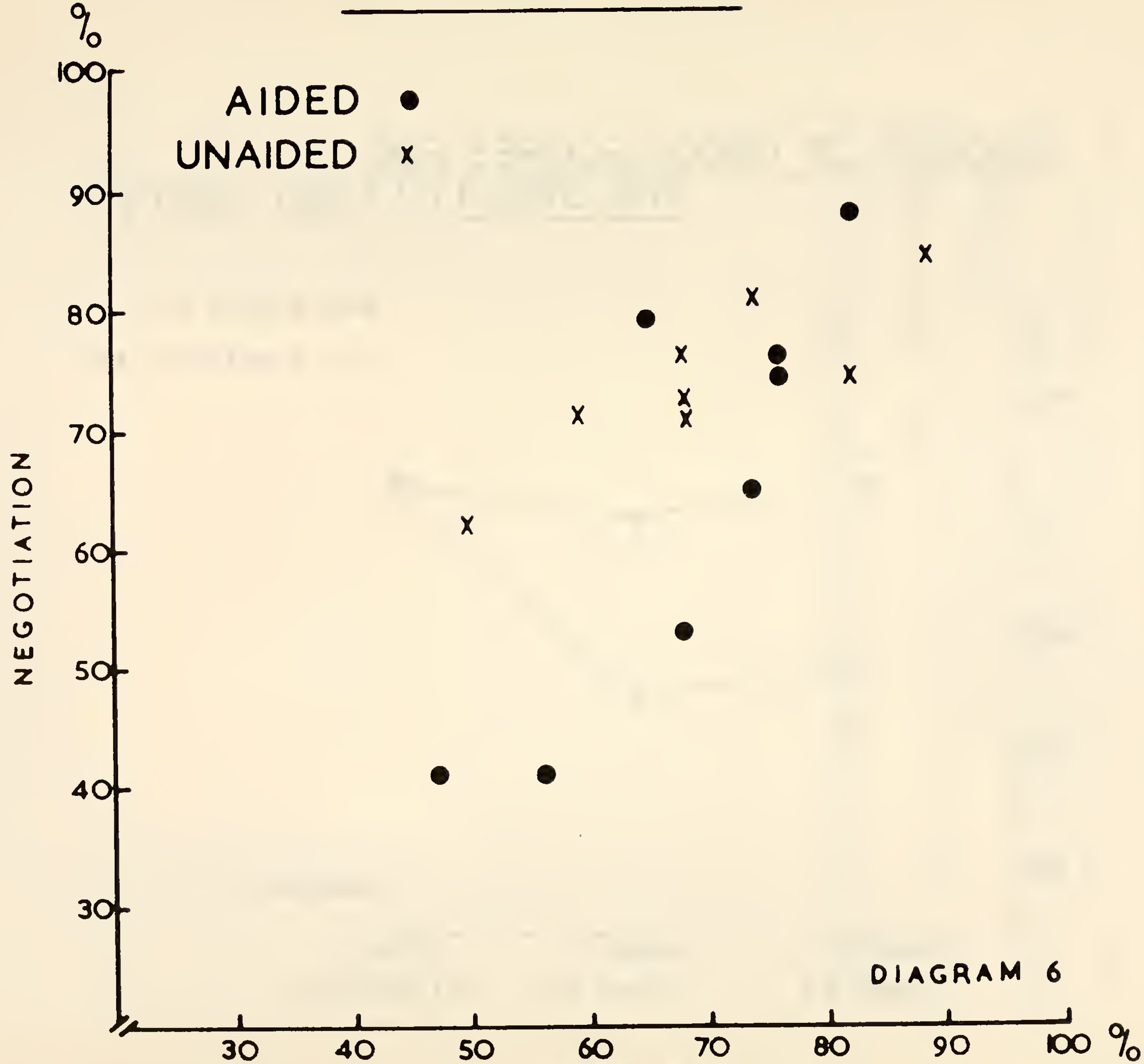


DIAGRAM 6

MEDIANS OF GROUP SCORES FOR 2ND, 3RD, 4TH POST TESTS

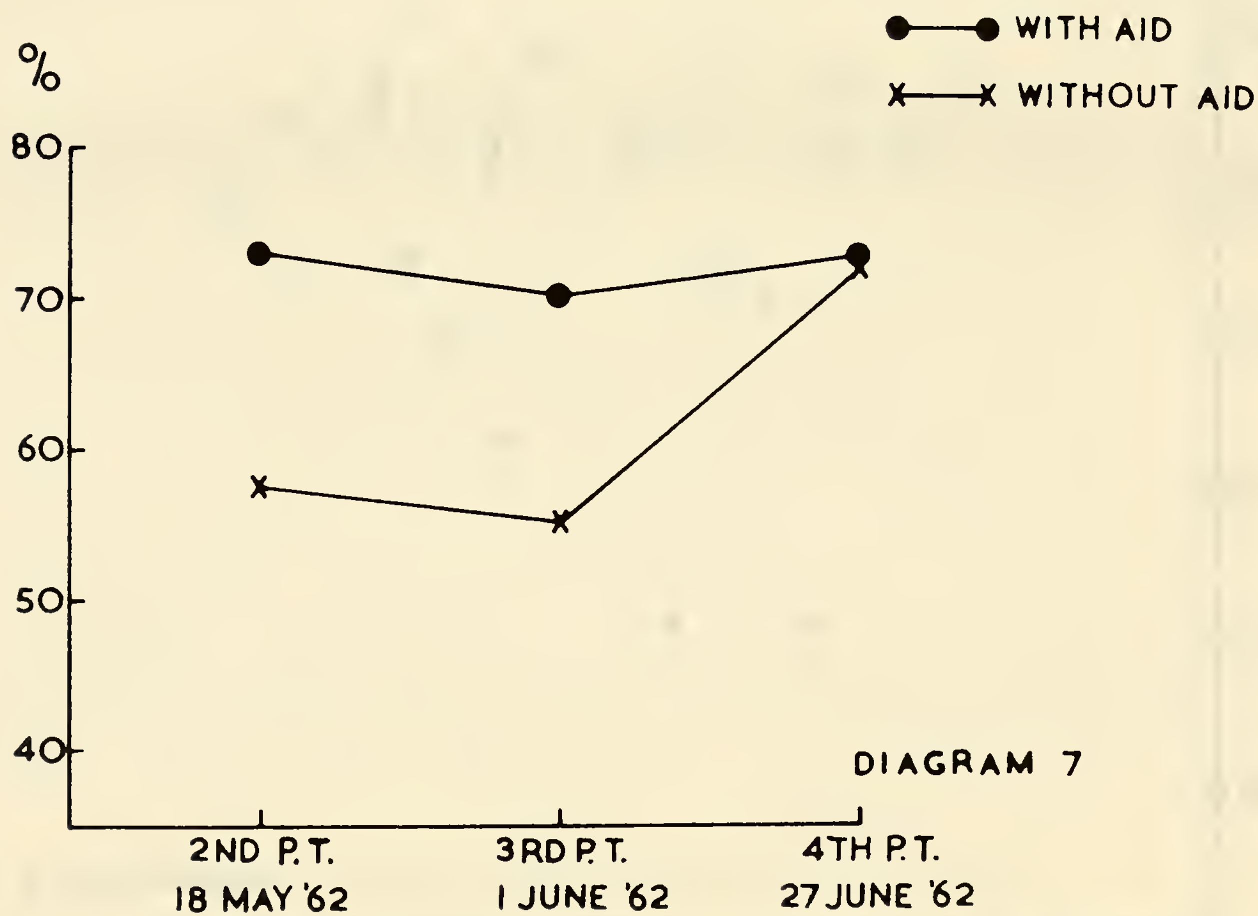


DIAGRAM 7

REFERENCES

1. Beurle, R. L. Electronic Aids for Blind People. Report to St. Dunstan's Sensory Devices Committee, 1952.

2. Kay, L., "Auditory Perception and its Relation to Ultrasonic Blind Guidance Devices," J. Brit. I.R.E., (1962).

3. Kay, L. Evaluation on F. M. Ultrasonic Guidance Aid for the Blind (Memo 117). University of Birmingham, 1962, (Department of Electrical Engineering).

4. Research on Guidance Devices for the Blind. New York: Haskins Laboratories, 1946.

5. Worchel, P. Space Perception and Orientation in the Blind. Psychological Monographs, No. 332, 1951.

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